MANAGEMENT STRATEGIES AND TECHNOLOGICAL AVAILABILITIES

Prepared for DAIMON

INTERNATIONAL DIALOUGE ON UNDERWATER MUNITIONS

Table of Contents

WP 4.1 Management Options

Introduction:

The DAIMON project partners will support maritime, defense and environmental administrations in making decisions on management strategies for dumped chemical and conventional warfare in the Baltic Sea, and the Skagerrak to assess the risk associated with corroding warfare objects, such as dumped containers filled with munitions.

DAIMON will focus on the evaluation of risks associated with individual munitions, categorization of threats, and possible remediation methods. Economical and legal issues will also be addressed with more details on legal issues in a separate task paper.

Risk assessment/categorization methods will be applied to produce examples of evaluation in different regions of the Baltic Sea. As the main result, an easy-to-use software, based on the research carried out within the project, will be presented to stakeholders (maritime administration, environmental agencies, etc.) in the Baltic Sea countries to provide them with a tool for the efficient management of the problems in their respective exclusive economic zones (EEZ). The tool aims at making the knowledge gained in previous projects related to dumped munitions available to decision makers in the Baltic Sea area thus making wise economical and environmental choices.

Management of the many diverse and complex underwater munition sites cannot be effective without the study of site specific conditions and the complete understanding of many legal aspects concerning marine munitions management, law of the sea, international, national and regional jurisdictions concerning safety, environment, existing legal frameworks and political factors. Choosing a strategy is site specific and depends on many factors (physical, legal and political) and conditions. It is strategic as such that it is not reactive to emergency situations; rather, it is based on structured and proactive measures to continually improve on multiple sites at the right time in the right priority. It places the correct resources to the planned priority areas in order to effect as much environmental restitution as possible.

The ability to locate and conduct site characterization is an extremely important first step in this process of determining a management strategy. The ability to accurately locate and characterize a site allows for accurate risk assessment. The evaluation of the risk(s) is an important factor, since not all sites require will remediation, but most will require risk mitigation planning.

Furthermore, technological advancements have cleared the way for safe, environmentally friendly, and cost-effective remediation of many of today's sites, while some sites may not be likely candidates for remediation due to environmental factors, risks, and high costs. Most importantly, detailed and updated historical reviews, site sampling, risk identification and mitigation consideration are necessary prior to any remediation of an underwater munitions site.

Technological advancements in the private sector have already demonstrated the ability to conduct safe, cost efficient, non-destructive remediation of sea dumped munitions, including their proper disposal. While there is no single technological approach to meeting challenges found at every site, it is no longer correct to universally dismiss considering non-destructive remediation for a lack of technology. There is no silver bullet that can address all aspects of an underwater munitions response program; therefore one takes the "Tool Box Approach"; whereas we reach into the toll box to select the right tool or a number of tools for the task at hand. (Helcom: Overview on Underwater….Military Munitions Response Programs pp 2)

The purpose of this paper is to describe six different management strategies available to decision makers in both a general and Baltic Sea context in making the appropriate strategy choice by providing:

- Description of each management strategy;
- Benefits and Risks:
    - environmental impacts (humans and biota);
    - technological resources; and
    - economic (scaleable) costs;
- Best approaches for remediation in various scenarios:
    - Conventional and Chemical Munitions in shallow, medium and deep waters; and
    - Shipwrecks in deep waters.
- Legal Limitations for Underwater munitions which will be mentioned in this paper but more detailed in a separate task paper.

DAIMON will use this information on designated underwater munition sites (known and unknown) regarding their impact on the environment and their cost vs. cost of no-action. Though costs are very important, it should not be a factor in choosing a strategy. For example, monitoring costs for one site may exceed that for a response action strategy of another. The most important factors on cost (value for money) is it's effectiveness on resolving the desired outcome and fiscal management in the planning and project/programme phases is paramount. The entire cost of a chosen strategy or option needs consideration as follows:

- Cost of doing nothing with existing and potential economic losses;
- Social and political trust and reputation of country(s) involved; and
- Cost of the project management process (planning, implementation and continuous monitoring as needed).

The management strategies adopted by DAIMON are:

0. No Action;
1. Monitoring;
2. Limiting Certain Actions at Sea;
3. Neutralization at Sea;
4. Detonation in Situ; and
5. Recovery and Destruction.

Management Strategies 0-2 are: **detection, characterization and sampling strategies** and 3-5 are **response action strategies**. In a general sense, costs of employing a strategy increases from 0-5.

There are different scenarios that can be applied to the management strategies and are dependant on the type of munition (conventional or chemical), if the munition is in shallow, medium or deep waters, and if the munitions are dispersed, clustered, buried in sediment or in a wreck. For example, employing the management strategy of Monitoring will have different costs in a scenario for shallow water than it would for deep water and also dependant on the disbursement of those munitions. Therefore, the various scenarios for the Baltic Sea are:

Table 1: Various Scenarios for the Baltic Sea

	Shallow Depth (0-9 m)	Medium Depth (9-152 m)	Deep Depth (>152 m)
Conventional	Dispersed, Clustered, Buried in Sediment	Dispersed, Clustered, Buried in Sediment	In a Wreck
Chemical	Dispersed, Clustered, Buried in Sediment	Dispersed, Clustered, Buried in Sediment	In a Wreck

1. No Action

1.1. Description

The strategy "No action" can be defined as the intentional or unintentional absence of disposal action with regard to munition management. Often times the strategy of "no action" is only considered in situations in which the negative consequences of taking action are higher than the probability of negative consequences when NOT taking action. Not taking action to manage the presence of conventional and chemical munitions does not necessarily result in beneficial situations, but is considered a viable option when considering water depth, munition type, location, and the likelihood of human exposure.

1.2. Risks and Benefits

No Action is a cost-effective approach from a strictly financial perspective. Leaving munitions undisturbed on the seafloor saves remediation expenditures, particularly if the objects are submerged at greater depths. No Action may have a more aggravating subsequent costs in terms of environmental impacts and the health and safety of humans if munitions are unintentionally surfaced since now the surfaced munition becomes an emergency rather than part of a well thought out management plan.

The No Action management strategy also mitigates against major environmental changes caused by anthropogenic activities. Leaving munitions undisturbed allows for gradual degradation and release within marine environments. This allows the contents of chemical and conventional weapons, as well as their secondary compounds and detonation agents, to release or deteriorate over a period of time. This time factor can be considered in choosing this strategy (ie. letting 'nature run its course'). Degradation products are generally less toxic than their parent chemicals, but arsenic does not undergo this decaying process and persists in sediment samples (M. I. Greenberg et al., 2016). Therefore, the no action strategy is not without its risks and does not eliminate all the hazards associated with underwater munitions.

The no action strategy can be beneficial in some situations. For instance, anthropogenic activity which attempts to recover or move underwater munitions interferes with the natural degradation processes. If the munitions on the sea bed have relatively thin walls, they can get pierced by corrosion. When these munitions are recovered and brought to the surface, they can either fall into pieces by the movement of these vulnerable materials or the contents could leak out as they are moved. In these cases, performing no actions on delicate munitions ensures that there is no sudden contamination event.

Furthermore, research and analyses regarding the presence of conventional munitions in shipwrecks or scattered in dumping areas concluded that the cargo was not only still deadly, but also prone to spontaneous or accidental detonations in the case of shifting of the cargo in the tides not to mention any seismic event. In these cases, the weaponry had deteriorated and destabilized over the years and was likely to explode after contact in the form of minimal pressure by slight movements (G. Ford et al., 2005).

A similar situation is occurring in Skagerrak, where four shipwrecks were investigated during an expedition. After World War II, several wrecks were dumped with chemical ammunition on board. Before 2002, an investigation was carried out in 1989 and results following that investigation showed no major signs of corrosion or change of the conditions of the wrecks. However, the most recent investigation (2002) did show that some of the ammunition found in the wrecks had pierced through by corrosion, increasing the possibility of content leakages in the form of chemical materials. This indicates that the release of chemical ammunition into the sea will have long-term consequences. Keeping this in mind, it is crucial that new inspections, assessments and other various types of investigations are carried out in the short term to analyze the effects on the environment caused by the presence of the wrecks and its contents (Tornes et al., 2002).

Furthermore, site sediments and hydrography differ and the No Action option needs great consideration in this physical context. For example, both dispersion and accumulation of contaminated organic matter and the release to and degradation of CWA in the environment probably take a different course. (Gotland and Gdansk Deep dumps which differ from those in the Bornholm Deep) (Beldowski, Long, 2012).

Gdańsk Deep is an example where monitoring alone will not be sufficient to reduce dangerous incidents with fishermen hauling up sulphur mustard bombs and those same munitions washing ashore. Following the 1954 incidents in the Bay of Gdańsk, the Polish press published several articles pointing at witness reports. The confirmed amount of dumped munitions in 1954 amounts to 60 tonnes, of which an unknown amount is probably chemical munitions (Barański 1997, Kasperek 1999). The area has been investigated by the CHEMSEA project (cf. Chapter 2.3.2.2.2). Based on magnetometric and acoustic scans, four wrecks and several dozens of munition-like objects were detected. Visual inspection of one of the wrecks identified it as a barge, which could have be scuttled with its load of munitions, while some of the other objects were identified as artillery shells. Pollution of the sediments around those objects is currently under investigation. The extent of sediment pollution is currently unknown. Anoxic conditions prevailing in the area limit the contact of any such pollution with marine biota, although it may still pose a risk for fisherman performing bottom trawling and industrial activity on the bottom. The area was not mentioned in the 1994 CHEMU report.

Leaving toxic ammunition undisturbed on the seabed can be self-defeating when activity at dumpsites disturbs the munitions. For example, drag nets used by fisheries can displace deteriorated weapons or bring them to the surface. Since future activity cannot be fully predicted, the no action scenario needs to be accompanied by supporting detailed standing operating procedures that inform and warn the fisheries, logistical, energy, and infrastructure development sectors of the economy and take appropriate measures to safeguard people and the environment.

The no action option is usually carried out to prevent further deterioration of the surrounding environment and not because of specific beneficial reasons. In fact, in many cases, different types of organisms (e.g. shrimps) can be observed close to these munitions. Although this might not have direct consequences for these organisms, long-term toxic effects from the chemical components included in these munitions lead to the degradation of these fish and the environment and indirectly to the degradation of human health as these shrimps are being consumed in the future (Aa et al., 2002). In the case of dumpsites located near breeding areas for fish - as is the case with regard to the Bornholm dumpsite in the Baltic Sea - the chemical materials in munitions can potentially biomagnify within the food web, directly affecting the rich fishing grounds used by fisheries.

No action can have consequences for tourists as well. Even though the likelihood of contact with chemical and conventional munitions is low, the consequences for individuals are extremely high when these encounters take place. In terms of risk management, a low occurrence with a high impact for equates to a medium to high risk. In this case, not taking action also means not taking actions to prevent incidents from occurring in the future and therefore ignoring a medium to high risk category. Taking no action action to address the problem at the core (removing the munitions from the seabed) leads to an increased probability of the presence of dangerous white phosphorus washing up on the beaches of coastal cities, further increasing the risk for beach goers and even recreational divers.

Finally, choosing for a no action option and leaving chemical weapons and other munitions on the seabed may pose a public relations problem for governments especially if another country is actually engaging in more proactive looking management plans.

1.3 Limitations for the Baltic Sea Area

Due to the multi-international presence in the Baltic Sea area, a No Action approach can create transboundary legal and political dilemmas given the proximities of the Exclusive Economic Zones (EEZs). The investment for action by pursuing a management option in one country could be greatly affected by the inaction of another and construed as deferring immediate responsibility in managing dumping sites which can jeopardize the multinational cooperation required for broad and effective remediation efforts. For this reason this option would need to be limited to those areas isolated from another country's boundary or jurisdiction or in accord with other stakeholder nations.

As described above, the no action option has its limitations in the Baltic Sea area considering the chemical biomagnification measured in the Bornholm dumpsite which may continue or worsen with no action and become unmeasurable due to lack of a monitoring strategy.

Although dumped chemical munitions were recovered in the 1960s in 1995, HELCOM recommended that chemical munitions should not be recovered due to their degraded state and the lack of suitable technological solutions for safely removing and destroying them. Even today, the risks associated with handling them are still high. For people working in the marine environment of the southern and western Baltic Sea (e.g., fishermen or workers involved in offshore construction activities), the risk of encountering chemical warfare materials cannot be ruled out. In a scenario such as this, although recovering the munitions may not be appropriate, other management strategies need be investigated.

1.4 Legal limitations

Legal aspects of no action need to be considered. The complexities of various treaties and individual Baltic EEZs regulations may have an impact on leaving munitions on the seafloor. Thorough legal consultation is required with affected states prior to the no action approach because it is now not a case that the dump site is not known but what are the relevant country(s) going to do about it and the reasons for this action. In order to be informed to choose this no action approach, ironically more is needed to be known about the site prior to adopting this strategy.

1.5 Technological Availabilities No Action

While No Action pursues no change in the course of daily business and no handling of dumped munitions, awareness of dumping locations and anticipative measures can still reduce damages if munitions are detonated, or are brought into contact with persons or objects. Prior to this strategy a known geographical and physical data must be known. The DAIMON project has a data set of known sites.

Additionally, the DAIMON project itself develops a package for dealing with munition incidents for navigators or workers on the Baltic Sea. Depending on the determined severity and urgency using the project package, other management or counteracting strategies can be deployed if necessary. It should be noted that this course of action would take place after the fact, in contrast with pre-emptive use of management technologies.

2. Monitoring

2.1. Description

In this context, monitoring is environmental and are the processes and activities that need to take place to characterise and monitor the quality of the environment. Environmental monitoring is used in the preparation of impact assessments, as well as in many circumstances in which human activities carry a risk of harmful effects on the natural environment. All monitoring strategies and programmes have reasons and justifications which are often designed to establish the current status of an environment or to establish trends in environmental parameters. In all cases the results of monitoring will be reviewed, analysed statistically and published. The design of a monitoring programme must therefore have regard to the final use of the data before monitoring starts.

All scientifically reliable environmental monitoring is performed in line with a published programme. The programme may include the overall objectives of the organisation, references to the specific strategies that helps deliver the objective and details of specific projects or tasks within those strategies. However the key feature of any programme is the listing of what is being monitored and how that monitoring is to take place and the time-scale over which it should all happen. Typically, a monitoring programme will provide a table of locations, dates and sampling methods that are proposed and which, if undertaken in full, will deliver the published monitoring programme.
There are a number of commercial software packages which can assist with the implementation of the programme, monitor its progress and flag up inconsistencies or omissions but none of these can provide the key building block which is the programme itself.
Monitoring operations can be conducted by utilising divers, autonomous underwater vehicles and remote operated vehicles launched from research vessels. Monitoring usually takes place in several phases, including test phases (to select the best technologies and methods for a particular environment), survey phase (to locate dump sites and objects of concern), and a monitoring phase (which collects information). Monitoring studies include the evaluation of habitat status, fish health, and modelling of possible threats to adjacent areas.

2.2. Benefits and Risks

A Monitoring Strategy can be viewed as a monetary deferment strategy and gives higher risk sites priority in funding. Monitoring could be permanent or it may be temporary and is dependant on environmental monitoring statistics and parameters remaining the same or changing. Changing circumstances for the worse may mean that this strategy may need to morph into more reactive management strategies.

There are costs to monitoring; however, other than no action, it is one of the least expensive. The cost of reviewing historical records to identify disposal sites would likely be relatively small, primarily involving personnel expenses. However, the cost of researching and monitoring identified sites could be substantially higher, involving the use of vessels to reach offshore areas, scientific equipment to gather seawater and soil samples at possibly great depths, specialized personnel trained in the operation of such equipment, and laboratory analysis of monitoring data. Research and monitoring costs would depend on numerous factors, including the geographic scope of the sites, their distance from the shore, the depth at which munitions are present, and the methodologies used to evaluate contaminants and associated risks. Considering that much is unknown about the quantity and condition of weapons dumped in the ocean, developing reliable cost estimates to respond to potential risks is, and will continue to be difficult without detailed site information.

Monitoring dumpsites is useful for several reasons. For newly discovered dumpsites, conducting complex hydrogeological investigations to identify munitions in the area and determine the level of environmental contamination is central to creating a comprehensive response strategy. Requiring samples and surveys requires progressively difficult technical solutions dependant on the dump site's depth and location. Collecting data through underwater surveys, mapping, sediment testing, and modelling extrapolates risk factors for the environment and human health. Monitoring operations can also determine how environmental and oceanological factors affect corrosion rates, leakage, degradation, and the spread of contaminants. This can inform other management strategies by identifying and prioritizing the most urgent and dangerous locations and munitions for remediation. This allows policymakers to deploy funding and resources to the greatest advantages possible.(CTE).

For known dumpsites, the continued monitoring of "hot spots" (such as Bornholm and Skagerrak) provides scientists and government officials with valuable and up-to-date information on the evolving threats and future challenges. This documents serious changes or developments in corrosion and release, while also providing new generations of students with hands-on training and education opportunities. Monitoring operations can also provide information to local authorities who can then advertise warnings to fishermen, first responders, and the general public. Therefore, establishing monitoring operations allows for the steady growth of expertise and the dissemination of knowledge about underwater munitions to future generations. It warns people who might not have been aware of the dangers.

Monitoring underwater munitions can impact various economic sectors as well. Mapping dumpsites and creating inventories of possible munitions and degradation products is useful for offshore economic expansion in the energy sector, particularly if oil and gas pipelines (like Nord Stream) will transect known dumping grounds or if wind farms and other renewable energy infrastructures are constructed (CITE). Having an extensive archive of information will aid in the planning stages and avoid potential disasters. The same benefits apply to marine transportation, including infrastructure expansion at port facilities or bridges for vehicular and pedestrian traffic. Monitoring dumpsites also aides fishermen because it provides evidence to establish pollution and contamination regulations for seafood or restrict activities in a particular location.

The limitations of this management option involve the opportunity costs associated with spending research funding in one area (versus spending it somewhere else). A feedback loop can be created, whereas monitoring operations conclude that further monitoring is needed. Over time this can overemphasize funding expenditure on information gathering, which siphons research money away from other possible areas (such as developing new recovery technologies or remediation methods).

While monitoring can be a beneficial strategy in managing stable dump sites, it does not proactively eliminate the problem. A decision tool would need to be developed to graduate from monitoring to a different strategy if the dump site were to further degrade thereby increasing costs for activities that would have had to be done anyway. In effect, it can be seen as a costly deferral tool similar to a problem that is over studied rather than solved.

2.3. Limitations for the Baltic Sea Area

Monitoring dumpsites is the first and most important step in understanding developing changes or status quo at a dump site and choosing a subsequent munitions management strategy if required. There have been many international programs (such as MERCW, CHEMSEA, and MODUM) which have provided a great deal of information and baseline statistics about the behaviour of chemical weapons in the Baltic Sea (CITE).

As discussed above, the limitations of this management option involve the opportunity costs associated with spending research funding in one area (versus spending it somewhere else) and can be particularly problematic in the Baltic Sea due to EEZ proximity and each country's interested in the actions of the other in this common body of water.

Monitoring itself can be limited by the resources available or the requirements of the monitoring site. If a dumping site is located deep, monitoring expenses and difficulties increase. Dumping sites further from the shore also pose problems in establishing permanent moorings needed for research ships. Lastly, the number of research ships available may also be limited for monitoring purposes. Due to the numerous EEZs in the Baltic area, cooperation and possibly collaboration with multiple countries is needed to prevent unnecessary work being performed or to utilize the available (specialist) equipment and vessels optimally. Recommendations 12-1 and 37-1, (HELCOM actions to improve the Baltic Sea) for example calls for cooperation and coordination of research vessel based monitoring in offshore areas and procedures for granting permits for monitoring and research activities.

Additionally, establishing permanent moorings for monitoring activities may be impacted by the depths of dumped munitions, the hydrodynamically active sea/sea bed and their placement which could be a nuisance in navigable waters. Due to EEZ proximities, the monitoring activities of one country may impact the economic activities of another therefore, establishing coordination and agreements would be beneficial for a holistic Baltic approach.

As with any non-response actions strategies, the dump site will still require limitations and precautionary actions to be taken. The HELCOM CHEMU recommendations from 1994/1995 have been reviewed and updated as follows and present some limitations for the Baltic Sea area:

Investigate

• Historical Research - new or additional information on the dumping of chemical warfare materials and the possible co-disposal of conventional munitions in the Baltic Sea is likely to be obtained by archival research as shown by the information on en route dumping in the Flensburg Fjord. The Contracting Parties are encouraged to carry out, support and facilitate historical research in national and international archives, especially to undertake efforts to get access to still classified documents of relevance e.g., in the archives of the WWII Allies.

• Technical Research – precise, site-specific data on the types, quantities, status and spreading of sea-dumped warfare materials and their constituents in the Baltic Sea. The Contracting Parties are recommended to carry out, support and facilitate technical research, e.g. within international projects, in known and suspected areas using technology specifically suitable for the task.

• Research Transfer – inter-regional sharing of information would increase the overall knowledge regarding the issue; technical research is needed to complement historical data to allow for well-informed risk assessments. Likewise, single findings of warfare materials should be cross-checked with historical references. The Contracting Parties are recommended to share detailed information on the findings both within and outside the Baltic Sea region taking into account the UN General Assembly Resolution A/RES/65/149. Furthermore, it is advisable to investigate dumpsites bordering the Helsinki Convention Area, e.g. the dumpsite off Måseskär.

• Analytical Capability – the further development of chemical analytical methods is needed as well as updating the ecotoxicological and physicochemical properties assessments. The Contracting Parties are recommended to support and facilitate the development of suitable analytical methods and improving analytical capabilities.

• Periodical Surveys - guidelines for the periodical performance of intrusive/ non-intrusive sampling and testing of suitable methods both in known and suspected dumpsites are necessary in order to establish trends and foresee possible changes in the environment in these areas. The Contracting Parties are recommended to support and facilitate the development of suitable guidelines for carrying out surveys and testing methods.

• Risk Assessments - suitable instruments and methods for site-specific risk assessments of selected dumpsites should be developed, taking into account the threats to humans and the marine environment, including possible acute, chronic and long-term effects. The Contracting Parties are recommended to support and facilitate the development of suitable instruments and methods for site-specific risk assessments.

• Intentional Recovery - with regard to the increasing use of the seafloor, the intentional recovery of chemical warfare materials, where applicable, might no longer be excluded as a site-specific management option in accordance with nationally accepted guidelines or the results of risk assessments, as seen in other areas for chemical munitions dumping. The Contracting Parties are recommended to transfer procedures and experiences for intentional recovery that exist under the provisions of current international legal instruments.

• Unintentional Catches - risks associated with unintentional catches of chemical warfare materials are still present for the crews of fishing vessels operating in the vicinity of dumping areas. The Contracting Parties are recommended that response teams should be deployed and that on their advice relocation of caught chemical warfare material may be considered as an acceptable emergency measure.

• Document Updating - with regard to ongoing national and international activities and projects, periodical updates of the HELCOM report on dumped chemical warfare materials will become necessary. The Contracting Parties are recommended to consider this report as a step in an ongoing process and to establish a working process for periodical updates after significant new information becomes available.

• Public Awareness - up-to-date information on sea-dumped warfare materials, including white phosphorus in the Baltic Sea region, and on-going activities should be provided via easily accessible public information at national and HELCOM levels, taking into account UN General Assembly resolution A/RES/65/149. Furthermore, specific local information should be available in areas of concern for the possible occurrence of white phosphorus such as tourist information leaflets and warning signs. The Contracting Parties are recommended to support and facilitate the development and operation of such information portals and other relevant measures to increase public awareness.

• Knowledge Provision - national centres or responsible organizations for the collection of information on sea-dumped warfare materials, the coordination of response and training activities for the decontamination of vessels and equipment, as well as the treatment of affected people are necessary. The Contracting Parties are recommended to support and facilitate such national centres.

• New Guidelines - increasing use of the seafloor for the construction of offshore facilities, such as wind farms and sea cables, bring new groups into potential contact with sea-dumped chemical and conventional munitions, necessitating new and updated guidelines for possibly affected groups. When active in the vicinity of areas with known or suspected contamination by chemical warfare materials, contingency measures for dealing with both chemical and conventional warfare materials should be in place. The Contracting Parties are recommended to carry out, support and facilitate the update and development of suitable guidelines for all potentially affected groups.

• Up-to-date Charts - technical investigations have provided and are still providing information on the actual positions of sea-dumped chemical munitions. No special code for chemical warfare materials will be available for future Electronic Nautical Charts. The Contracting Parties are recommended to update sea charts to reflect the extensions of primary and secondary dumpsites, and to ensure that no information is lost on nautical charts when the transition to Electronic Nautical Charts is made.

2.4. Legal limitations

Due diligence is the standard of reasonable care or reasonable steps that a person (or organization, jurisdiction etc.) exercises to avoid harm to others and/or the environment. It can be a legal obligation or more commonly applied to voluntary investigations. The theory behind due diligence holds that performing this type of investigation contributes significantly to informed decision making by enhancing the amount and quality of information to decision makers and by ensuring that this information is systematically used to deliberate in a reflexive manner on the decision at hand (choice of management strategy) and all of its costs, benefits and risks. In this context, through monitoring dump sites, countries may be able to defend a charge of non-compliance with the various laws or treaties applicable to their jurisdiction if they can demonstrate that they have undertaken due diligence to a necessary standard.

According to Beldowski et al., “Demonstrating due diligence is an important aspect of contaminated site management and is directly tied to continually understanding any potential risk to human or environmental health originating from a contaminated site”.

Beldowski et al, also mention that another situation (benefit) where monitoring is employed is at site boundaries between property owners (which would be applicable in the Baltic region) where migration of contaminants across jurisdictional areas could be a source of legal consequences.

As with most aspects of law, proving damages from someone (jurisdiction) places such burden of proof on the entity making a damage claim. So for example, a munition washing up on shore and causing damages (human injury or costs of response actions) it may be more difficult to prove from which jurisdiction that munition originated from and/or to what standard was employed to minimize or eliminate that risk.

2.5. Technological Description of Monitoring

There are plenty of technologies that can be used to monitor and survey underwater munitions. These vary from technological methods and equipment for divers to vehicles and submersibles.

Divers can make use of specialized underwater heavy equipment for both shallow and deep-water. For instance, divers may use either SCUBA (Self-Contained Underwater Apparatus), supplied air or one atmosphere suits. These suits make use of normal air of various gas mixtures and enable divers to reach a depth of approximately 30 meters. To extend their capabilities, SCUBA divers can also make use of TRIMIX and HELIOX systems. These extend the depth of the divers capabilities beyond 50 meters.

Technology also exists for occasions in which a depth greater than 90 meters have to be reached. In this case, divers would require a Deep Diving System (DDS). This system is especially developed for extended work time and deep depths. A DDS uses a Deck Decompression Chamber (DDC) that is mounted on a surface-support ship. This DDC is connected with a Personnel Transfer Capsule (PTC), which enables two or more divers to be lowered to the working depth.

At depths of over 300 metres, the Newt Suit can be used. This is a type of Atmospheric Diving Suit (ADS), allowing the diver to work at normal atmospheric pressure.

In special cases divers can even be replaced by a variety of technological devices and underwater vehicles, some even capable of operating at depths of 2,500 meters in the ocean. One of these underwater vehicles is the Underwater Towed Vehicle (UTC). This is a frame containing sensors, cameras and sampling equipment that are mounted in order to be towed through the water by a surface ship.

Technological development also enables the use of autonomous underwater vehicles (UAV). These are unmanned or in some cases even robotic vehicles that use sophisticated technology, expanding the capabilities to work in the subsea environment.

Moreover, Remote Operated Vehicles (ROV's) can be used. These are unmanned, but require an operator that remotely pilots the vehicle. A specific type of ROV is the “Crawler”, which works on the surface of the seabed and uses a track assemble to move and operate at depths to 1,000 meters. For shallow underwater applications the C-TALON was designed, which is a smaller version of the Crawler.

The autonomous and remotely operated underwater vehicles mentioned above are especially effective at detecting, mapping, recording and tracking of underwater munitions and munitions debris in real-time.

Where maneuverability is very important for a project, Submersibles can be used. These are highly effective at covering significantly larger survey swath widths. Moreover, they increase detection capabilities. Submersibles need a crew to operate and make use of observers who perform the actual mission. Because of their size, submersibles have small windows (viewports) that can be used to gather specimens or samples.

Besides the use of vehicles and equipment for divers, the field of specific underwater technologies has been developing and improving as well. Today, underwater sensors can effectively scan and monitor large areas. Technological development even enables the use of sound.

For instance, the IMI-120 Side Scan SONAR is able to scan targets that are 1 to 2 meters long on the seabed at an altitude of 75 meters. The SONAR is able to do this at a search width that is 10 times the towfish altitude, allowing for a coverage of 2.7km of seafloor to be monitored per hour. Another technological advancement related to SONAR is the use of Synthetic Aperture Sonar (SAS), that moves a sonar along a line and illuminates the same spot on the seafloor with several pings, that allow for the high-resolution mapping of specific areas.

For scanning, mapping and monitoring ferrous items of ordnance that has been dumped at sea and has settled to the sea bottom under layers of much, Magnetometers can be used. Magnetometry has been proven to be effective in detecting ferrous items in Europe. Ferrous items distort the magnetic field in the sea. Magnetometers can detect these distortions.

Hand held instruments making use of SONAR and Magnetometer technologies exist as well. These are easy to obtain and to employ and enhance the search capabilities of the diver.

These technologies and the resources required are illustrated in the various columns of the **Availability of Technologies Table** in the appendix. This table provides the descriptions of technologies available for different strategies at depths they are normally used at. The depths of the Baltic Sea are in the **shallow (S)** (0-9 m) to **medium (M)** (9-152 m) to **deep (D)** (152-305 m) ranges. The deep range is specifically for Skagerrak with scuttled wrecks containing munitions (chemical and conventional). The management strategy in the table numbering is as follows:

0. No Action;
1. Monitoring;
2. Limiting Certain Actions at Sea;
3. Neutralization at Sea {covering (conventional), enclosure (chemical)};
4. Detonation in Situ (conventional); and
5. Recovery and Destruction.

This numbering system is within the table to associate the management strategy to the technology.

2.6. Technological availability

The ability to detect underwater anomalies can be a difficult undertaking, made more difficult as the depths increase. The evolving dynamics of the oceans themselves must also be considered. This is especially applicable in the Baltic Sea. Weather, underwater currents, marine growth and the effects of shifting bottom conditions only increase the problems in trying to locate and recover material that has been deposited on the ocean floor decades ago. Furthermore, the complexities of equipment themselves are susceptible to malfunction and difficult to repair without expert advise. There are also human factors such as with human susceptibility in personal abilities and error.

Wide Area Detection Technologies:

There are a variety of surveying/detecting techniques for detecting underwater munitions. These tasks can be accomplished from a variety of platforms. To some degree selection of the platform is contingent on the nature of the task and the depth of the operation. The platforms include:

- Divers
- Underwater towed vehicles (UTV)
- Autonomous underwater vehicles (AUV)
- Remote operated vehicles (ROV)
- Submersibles

However, those most commonly used in depths greater than 30.48 meters are towed or self propelled vehicles to which sensors have been built in or attached.

The types of survey detection (wide area and localized) has been greatly enhanced through technological improvements. The technology to rapidly survey vast areas at various depths is available today and is being used by governments, academia, and businesses worldwide. In addition, the development of sonar technologies has now reached a level where extremely detailed resolution can be achieved utilizing computer enhancement. One of the best current examples of conducting an underwater survey to detect a suspected toxic chemical munitions underwater dump site is the work that has been achieved by the Hawaii Undersea Military Assessment (HUMMA) http://www.soest.hawaii.edu under the administration of the University of Hawaii.

Types of survey detection devices include SONAR, Synthetic Aperture Sonar (SAS), Magnetometers (detecting ferrous items), Data Fuzing (combining data of SONAR and Magnetometer).

The following are descriptions of the various equipment and technologies that can be used in underwater munitions survey and detection:

Diving

Divers may use either SCUBA (Self-Contained Underwater Breathing Apparatus), supplied air or one atmosphere suits.

Each option has its advantages and limitations, The greatest concern associated with using divers in munitions operations is their vulnerability should an accident occur. Diving carries a number of hazards in and of itself and the danger from munitions is exacerbated underwater.

Figure 1: Typical Scuba Diver (with or without mixed gas)

SCUBA divers can utilize either normal air or various gas mixtures. The use of normal compressed air allows SCUBA divers a limited amount of time and depth. While using normal air the diver is limited to approximately 30.48 meters and is limited to the amount of air that he can carry. A surface supplied diver has an unlimited supply of air.

Mixed gas diving was developed to extend past the 0.8 meters limit and to extend divers time on the bottom. TRIMIX and HELIOX systems extend the depth of the divers operational capabilities beyond 50.29 meters. Divers are subject to the water temperature, pressure, currents, and other environmental factors present at their diving depth. Work time varies due to the pressures excreted and the dangers of decompression sickness (The Bends) if a diver surfaces too fast. The use of NITROX and HELIOX reduces but does not eliminate the danger. The normal operational limit for mixed gas dives is 91.44 m. At that depth, the bottom working time is limited to approximately 30-minutes.

Figure 2: KOBE Diver in a Chemical Weapons Wet Suit

At depths greater than 91.44 m **Saturation Diving** is a diving technique used which allows longer, deeper dives and more ambitious underwater tasks to reduce the risk of decompression sickness. Examples of saturation missions include submarine rescue and salvage, construction, and scientific testing and observation. These types of operations are characterized by the need for extensive bottom time and, consequently, are more efficiently conducted using saturation techniques. The identification and recovery of munitions at depth beyond 91.44 meters would require saturation divers operating from a Deep Diving System (DDS). This system was developed to support extended work time and deep depths for extended periods of time. The commercial market for this technology is in the Ocean Oil & Gas Industry.

The Deep Diving System consists of a Deck Decompression Chamber (DDC) mounted on a surface-support ship. A Personnel Transfer Capsule (PTC) is mated to the DDC, and the combination is pressurized to a storage depth. Two or more divers enter the PTC, which is unmated and lowered to the working depth.

Figure 3: Diving Bell

The interior of the capsule is pressurized to equal the pressure at depth, a hatch is opened, and one or more divers swim out to accomplish their work. Depths of up to 304.8 m can be achieved for extended periods of time.

Figure 4: Atmospheric Diving Suit (ADS)

The Newt Suit is a type of Atmospheric Diving Suit (ADS), developed by the Canadian engineer Dr Phil Nuytten in 1987. It is constructed to function like a 'submarine you can wear', allowing the diver to work at normal atmospheric pressure even at depths of over 300 m. One-atmospheric diving suits consist of a cast aluminum exoskeleton outfitted with fully-articulated joints so the diver can move more easily underwater. It is constructed to function like a 'submarine you can wear', allowing the diver to work at normal atmospheric pressure at depths of over 304.8 m and eliminates the need for decompression. The life-support system provides 6–8 hours of air, with an emergency back-up supply of an additional 48 hours.

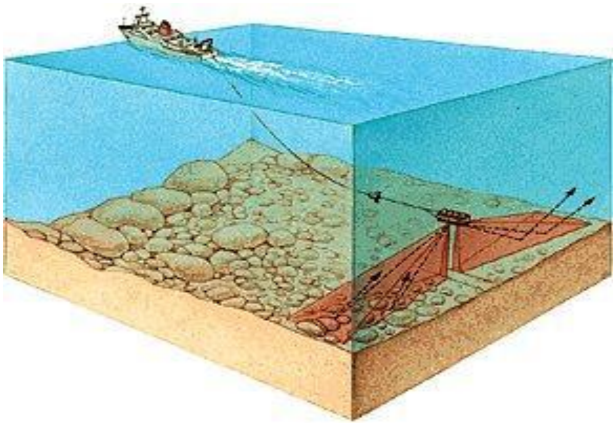
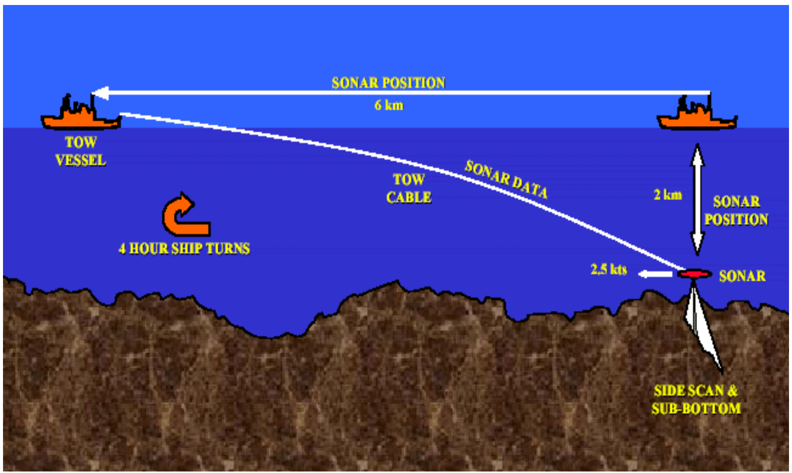


Figure 5: Underwater Towed Vehicle (UTV)

A UTV is simply a frame containing on which sensors, cameras and sampling equipment can be mounted in order to be towed through the water – usually by a surface ship. Depth of use is limited by the cable which makes positioning difficult at deeper depths. UTVs have limited maneuverability. Sophisticated UTVs are fitted with control surfaces or wings which help stabilize the motion of the body and alleviate the effect of the surface ship "heaving" on the cable in high sea states.

The longer the length of tow cable the greater the drag, and the wider and slower the turns must be at the end of a survey line which can significantly affect productivity. A deep tow can require from two to six hours to make a 180-degree change in direction. Direction changes typically consume up to 50 percent of the time on a deep tow project. The advantages of UTVs over other vehicles is real-time man in the loop data acquisition, power is supplied by the tow vessel



and is essentially unlimited, and the platform is relatively inexpensive to construct.

Figure 6: UTV Operation

At depths of less than 2,600 feet, UTVs are often acoustically positioned from the tow vessel; alternative methods must be used at greater depths. A UTV survey can be time intensive and require an significant logistics and operational planning. This is particularly difficult when using a deep tow in rough terrain. If the deep tow is too high, data quality will be poor. If the deep tow is too low, cross track coverage is limited and the possibility of colliding with the bottom becomes much higher.

Autonomous Underwater Vehicle (AUV)

AUV stands for autonomous underwater vehicle and is commonly known as unmanned or robotic underwater vehicle. AUV can be used for underwater survey missions such as detecting and mapping submerged wrecks, munitions, and obstructions that can be a hazard to navigation for commercial and recreational vessels. An AUV conducts a pre-programed survey mission over an area of the seafloor without operator intervention. When a mission is complete, the AUV will return to a pre-programmed location where the data can be downloaded by the operator and processed by a geophysicist depended on the AUV company.

AUVs are are using state-of-the-art technology to bring new capabilities to work in the subsea environment. In the past 30 years, 1000s of AUVs have been built. Most of these systems have been experimental. However, they have achieved impressive results and this record of success is creating a demand for their use in operational settings.

Figue 7: IVER, AUV, 3rd International Dialogue on Underwater Munitions, Sopot, Poland

Figure 8 : IDUM Photo NATO SPS MODUM Deploying IVER and Mag from Oceania

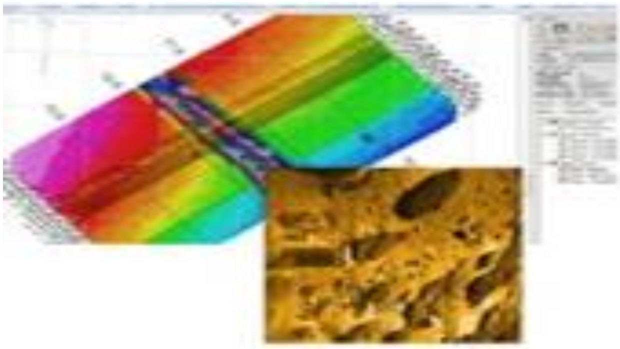


Figure 9 : Mag and Side-scan Data

The AUV's purpose is to carry a payload. The specific composition of the payload will be determined by the mission of the vehicle but can include instrumentation to measure ocean water characteristics, map the seabed or inspect subsea installations such as pipelines.

The AUV resembles a torpedo in many respects. It contains a propulsion system consisting of one or two thrusters, control surfaces, which act like wings to control the vehicle's attitude, a pressure hull to contain electronics and power, and a streamlined fairing to reduce hydrodynamic drag. The vehicle is self-sufficient. This means that it carries its own energy source and is programmed with a set of instructions that enable it to carry out an underwater

mission without assistance from an operator on the surface. Included in these instructions is information necessary for guidance and navigation between pre-determined geographic positions, procedures to avoid obstacles, and actions to be taken in case of equipment breakdown. Procedures for the operation of the payload devices are also provided.

The autonomous and remotely operated underwater vehicles are known for their low operations and maintenance costs. They are employed today with many of the Worlds

Navy's for Mine and Countermine (MCM) measures for detection, mapping, recording and tracking of underwater munitions and munitions debris in real-time.

Some companies employ geophysicist/s to operate AUV and to post-process their collected data that can reduce daily, weekly, or monthly costs or charge-out rates. For long-term, wide area monitoring projects, the purchasing of AUV/s and training personal for tasks may be more cost effective then renting equipment or contracting a company.

AUV's are cost effect! First, only one vessel is required. The AUV mother ship, transits directly over the AUV (just like the "chase boat" tracked over the towfish). Cost and logistics are reduced substantially when the tow vessel, tow cable, winch, etc. are eliminated.

AUV's can be designed to survey from surface down to Ocean Depth. Their costs increase by the greater the depth combined with the AUV own autonomous self-reliance technology, such as obstacle avoidances or satellite tracking. Sensor technologies costs need to be considered whereas, the cost can change from one manufacturer to another manufacture or the same sensor or difference sensor that provides the same survey result. Sensors can include, but not limited to, side-scan, synthetic aperture, acoustic, multibeam and magnetometer technologies.

Multiple sensors to an AUV to increase your data collection options and quality, whereas, you can layer data sets to better understand a potential target or anomaly, however costs will also increase, but not always proportionate to the data collected. Water quality sensors for gases, PH, ORP, CTD, salinity, methane, radiological and many others sensors can be fitted to an AUV. Some AUV's can hover to collect samples or relocate anomalies, including munitions from the seafloor.

The survey time with the AUV is dramatically reduced over conventional towed systems in two ways:

First, the Survey Speed of the AUV is much higher than a deep towed sonar. A deep towed fish is limited to about 2.5 kts. At faster speeds, the towfish will tend to rise towards the surface, making it too high from the bottom to get good data. Alternatively, the AUV surveys at 4.0 knots, or about 60 percent faster than a deep tow.

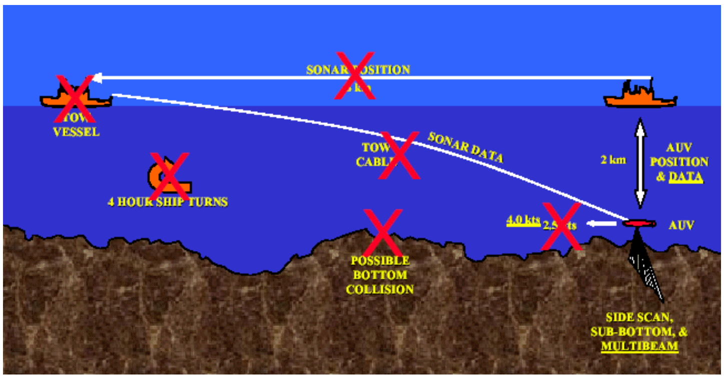


Figure 10: AUV Operation

When an AUV is used instead of a deep towed platform, the project is greatly simplified. First, only one vessel is required. That one vessel, the AUV mother ship, transits directly over the AUV (just like the "chase boat" tracked over the towfish). Cost and logistics are reduced substantially when the tow vessel, tow cable, winch, etc. are eliminated. Second, line turns take far less time for an AUV than for a deep towed sonar. Deep tow systems require from two to six hours to make a 180-degree turn. Historically, up to 50 percent of the time spent on a deep tow project is used for line turns. On the other hand, the AUV can make a line turn in just a few minutes. The effect of the faster survey speed and the quick line turns can reduce the required survey time by about 60 percent as compared to using a deep tow.

One of the difficulties of using a deep towed sonar is getting onto, and staying on, the survey line. In fact, because of the difficulties associated with deep-towing a fish, rarely are the data from the first line of a deep tow project worth keeping. Currents often push the towfish off line by hundreds of meters. If a target is missed, it requires a long slow turn and a great deal of luck to come relatively close to the target.

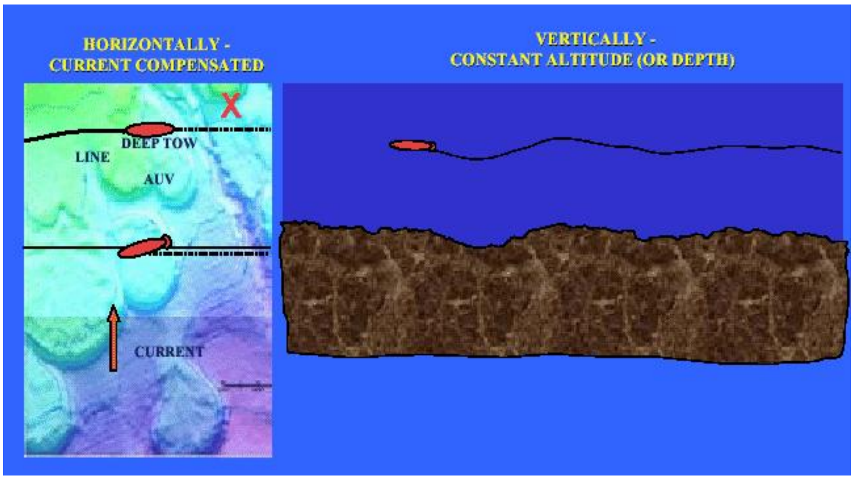


Figure 11: AUV Operation

The AUV may crab just a bit to overcome the currents, however, it will stay within a few meters of the programmed line.

During the MODUM project, 36 detail survey and identification missions were conducted with a usage of the IVER2 AUV, in the areas of Bornholm Deep, Gotland Deep, Gdańsk Deep and Little Belt. Total coverage area of those activities was 8.4 square kilometers and 742 potential bottom-lying targets were selected, based on collected data. The average density of the targets per square kilometer was 143 [1/ km2].

Larger Autonomous Underwater Vehicles – such as the HUGIN’s are considered marine robots that offer the ultimate in autonomous remote subsea survey capability. These free-swimming autonomous underwater vehicles are characterised by great manoeuvrability and high accuracy of stabilisation. Hydrodynamic shape, accurate instruments and excellent battery capacity makes these AUV's ideal choices.

The survey is also improved because the AUV can maintain a constant height off the ocean bottom. This is particularly difficult when using a deep tow in rough terrain. If the deep tow is too high, data quality will be poor. If the deep tow is too low, cross track coverage is limited and the possibility of colliding with the bottom becomes much higher. Additionally, if the deep tow has a multibeam sonar, varying towfish height will result in data gaps between lines that are very time consuming to fill. Alternatively, the AUV can be preprogrammed with three-dimensional survey line information or track the bottom and adjust its depth to maintain a constant height off bottom.

HUGIN's are available in several configurations and depth ratings. The main depth ratings are:

- 3000 m
- 4500 m
- 6000 m

Figure 12: International Dialogue on Underwater Munitions Mobilizing HUGIN

Figure 12 is the HUGIN sitting in its launch and recovery system ready to launch. Because IDUM's HUGIN autonomous underwater vehicles can function without tethers, cables, or remote control, they have a multitude of applications in oceanography, environmental monitoring, and underwater resource studies. A key element in the HUGIN concept is the application of a common technology that makes the systems adaptable for navy and commercial applications. IDUM's modular design allows different payload configurations, depending on the customer's needs.

In summary, the numerous advantages of the AUV over deep tow systems include:

- Elimination of a second vessel
- Faster line turns
- Faster survey speed
- No tow cable, winch, or associated handling systems
- Fewer data gaps
- No radio telemetry
- Greater maneuverability
- Terrain-following

Remote Operated Vehicles (ROVs)

Figure 13: Remote Operated Vehicle

A remotely operated vehicle (ROV) is an unoccupied underwater robot that is connected to a ship, wharf or plat-forum by a series of cables. These cables transmit command and control signals between the operator and the ROV, allowing remote navigation of the vehicle. An ROV may include a video camera, lights, compass, INS, samplers, sonar systems, and articulating arm/s. The articulating arm is used for retrieving small objects, cutting lines, or attaching lifting hooks to larger objects, relocating or recovering munitions or setting charges to blow-in-place. Cost will change similar to AUV's, as technology, manufactures, countries, legal requirements, depth, taxes and end use requirements change.

While there are many uses for ROVs, some of the most common hydrographic applications include object identification (for submerged navigation hazards) such as the recovery, relocate and disposal of underwater munitions. An ROV is not intended to be a replacement for a diver investigations, but serves as a substitute if divers are not available or diver safety is in question. ROV are use today to inspect, sample, relocate or recover chemical and conventional munitions. Costs are a consideration when determining what approach to employ.

Both the costs of divers and ROV's can increase with depth, but the risk to a diver can determine the final approach, which is not away the most economical approach. Other considerations for costs, include training and qualifications, mobilization and demob, local considerations, regulations, client's requirement or end use and the duration of the survey or monitoring.

While there are many uses for ROVs, some of the most common hydrographic applications include object identification (for submerged navigation hazards) such as the recovery, relocate and disposal of underwater munitions. An ROV is not intended to be a replacement for a diver investigations, but serves as a substitute if divers are not available or diver safety is in question. ROV are use today to inspect, sample, relocate or recover chemical and conventional munitions. Costs are a consideration when determining what approach to employ.

Generally, one or two manipulators are fitted to the vehicle for work, and on many vehicles, specialized work packages or 'skids' are fitted below the vehicle.

The ROV was first developed in the late 1950s. Commercial use of the technology started in the mid '70s and shortly after its use was commonplace. Several thousand vehicles have been built and are in use with scientific, military and commercial organizations.

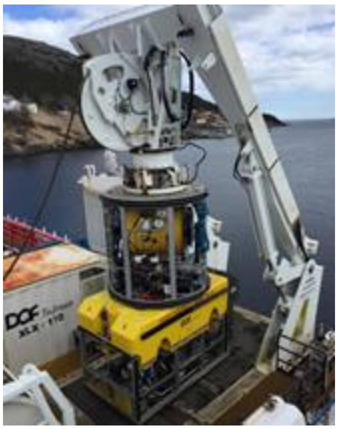
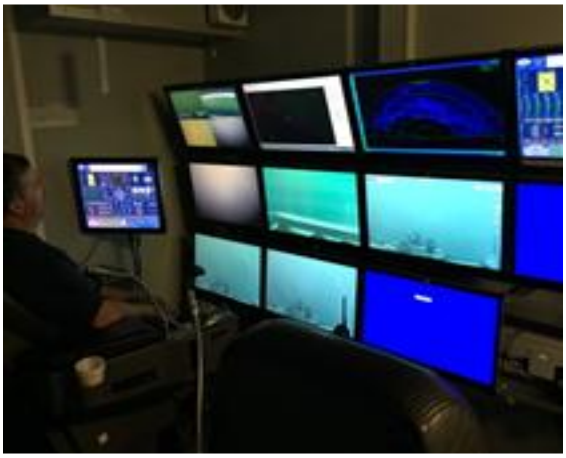


Figure 14: ROV Perry 4000' UXO Marine Inc.

The umbilical is one of the vehicle's biggest assets, and at the same time, one of its biggest drawbacks. Because the ROV is physically connected to the surface, large amounts of power can be sent to the vehicle and large amounts of data can be received. Working against this, however, is drag on the umbilical and more power is required as depth or speed is increased. For ROVs, which must operate in deep depths or in high currents, a substantial cable winch and power generator is required, and this again results in the need for a sizable surface support ship. ROVs are best suited for work which involves operating from a stationary point or cruising at relatively slow speeds - on the order of 1 meter per second or less. For any tasks involving manipulation and requiring maneuverability, they are the most cost-effective platform. They can work directly over an underwater munitions site to carry out a detailed survey and investigation allowing for higher quality data and sampling.



The combination of a manipulation arm that allows the remote movement of material and the use of highly sophisticated cameras are best in the sampling process and in actual remediation. This is where the use of ROVs is beneficial.

Figure 15: ROV Control Centre, UXO Marine Inc.

Figure 16: Photograph of a DMM being examined by the Nereus HROV at a depth of approximately 800 m during operations off the coast of Hawaii (image courtesy of Andy Bowen, WHOI).

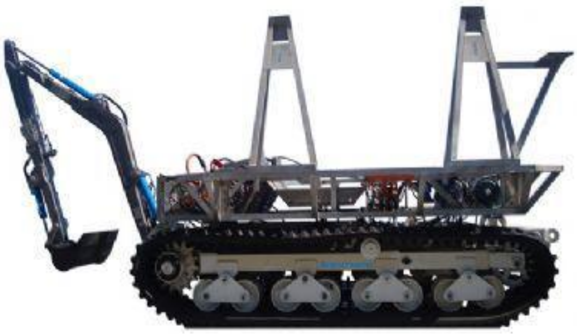
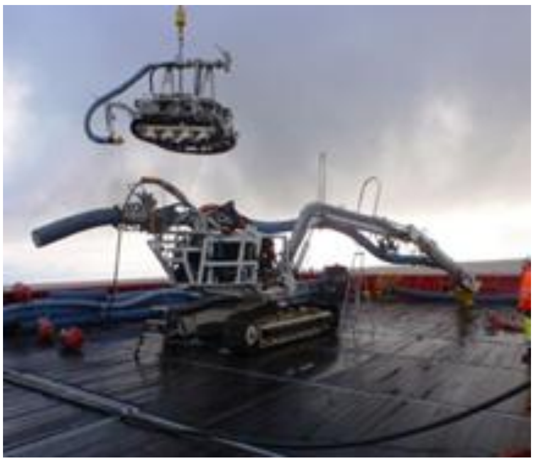


Figure 17: Crawler ROV



Another type of ROV is a “Crawler”. Instead of moving about by electrical propellers and operates in the water column. It works on the surface of the seabed and moves about on a track assemble. The British firm that has developed this technology, Reef Subsea UK Ltd.

Figure 18: Crawler - Courtesy of International Dialogue on Underwater Munitions

www.scannmudring.com is currently using this technology in the North Sea to support work with the Oil and Gas industry. The Scancrawler system is a tool carrier for hydraulically operated tools, it can operate at depths to 1,000 meters. Various tools such as suction ejector systems and special hydraulic operated tools (bucket, gripper, water jet cutters, drill, blower, drum cutter, back flush).

A smaller version of a crawler ROV also exists, the C-TALON http://www.qinetiq-na.com was designed for shallow underwater applications. Lakes, rivers and surf areas can be surveyed using this existing technology.

Submersibles

The decision as to which tool to use depends upon the requirements of the project, the depth, terrain, mobility of target objects or organism, type of surveys, type of collecting, and deployment or recovery of instruments. A widespread misconception is that ROVs are in all cases superior to submersibles and will completely displace the latter in the future. In reality, different projects require different tools. ROVs are indeed superior to submersibles at deeper depths (below 2000m) since they have a continuous power source. ROVs are also superior for projects with very long transect requirements for the same reason. ROVs can be safely operated at night as well as day, and are essential for conducting nocturnal surveys. ROVs are at least equal if not better than submersibles for low relief continuous substrate surveys such as over sediment where maximizing transect width is less important than it is in mixed terrain.

However, submersibles with trained experienced observers can dramatically increase survey swath widths and detection capabilities. The human eye is by far the most efficient visual survey tool currently available. Submersibles with trained observers are significantly better at surveying bottom features and munitions that are encrusted with marine growth.

Figure 19: Submersible Vehicle

Submersibles are far superior in extreme relief where concerns of snagging tethers are significant. Submersible can sample on vertical and overhanging walls where many deep water corals and sponges are found and where ROV operators are rarely willing to risk their vehicles. Submersibles are superior where maneuverability is very important to the project.

Unlike an AUV, a submersible has a crew to operate it and usually carries one or two observers who perform the mission. Submersibles have viewports (small windows) through which observations can be made and manipulators which are used for mission tasks such as gathering specimens or samples. Submersibles are highly maneuverable. Like the AUV, it is self-sufficient, and carries its own power as well as crew life support equipment.

Because human operators replace computers, submersibles are generally much larger than the other platforms. This results in the need for a large surface support ship and thus, operating costs are higher than for the other platforms.

In the 1970’s submersibles were used extensively by the military, the offshore oil industry and scientific research agencies. However, the rise of the ROV allowed much of the work previously done by submersible to be conducted at lower costs and today submersibles are used principally for scientific research. Fewer than 20 submersibles are remain in operation, with most being used by major oceanographic institutes.

Ocean Depth Manned Submersible

The Five Trench Dives and Beyond

Pentarius was first conceived by explorer Steve Fossett to set the record of the deepest solo dive, then shelved unfinished when he passed away. A chance meeting led to a revival and expansion of the project to include diving worldwide and science goals, especially in the areas of documenting munitions dumping and raw discovery - going to the deep, undocumented areas in the open ocean. Their goal is to provide funds for International Dialogue on Underwater Munitions (IDUM), a Foundation, to clean-up underwater chemical and conventional weapons by creating public awareness with underwater video of the decaying sites.

Figure 20: Pilot, Sailor, Explorer Chris Welsh, Deep Sub LLC

The Pentarius is designed to go really deep, 36,000 feet down to Ocean Depth, anywhere in the world. Seamounts, trenches, undersea vents - our goal is to see it all and bring that experience back to the surface for everyone to see. Pentarius’ main mission is trench diving - exploring the 30,000 miles of trenches that encircle the Earth.

Pentarius has a carbon fiber cylindrical pressure vessel with an aluminum hemisphere at one end and a fused quartz hemisphere at the front. The hull is flooded, and the rest of the components (batteries, motors, and control servos) are oil filled but subjected to full ocean pressure. This saves the weight of creating pressure protection for each of these components.

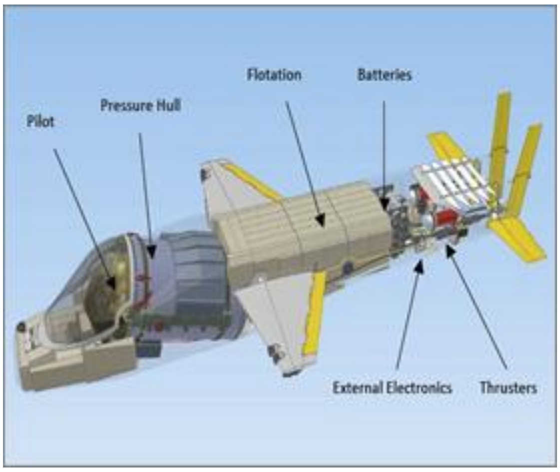


Figure 21: Pentarus diagam

The pressure at full ocean depth (FOD), is 16,000 PSI. The two hemispheres exert 15,000,000 pounds of compression on the carbon cylinder - the weight of three fully fueled space shuttles!

Survey Detection (wide area and localized)

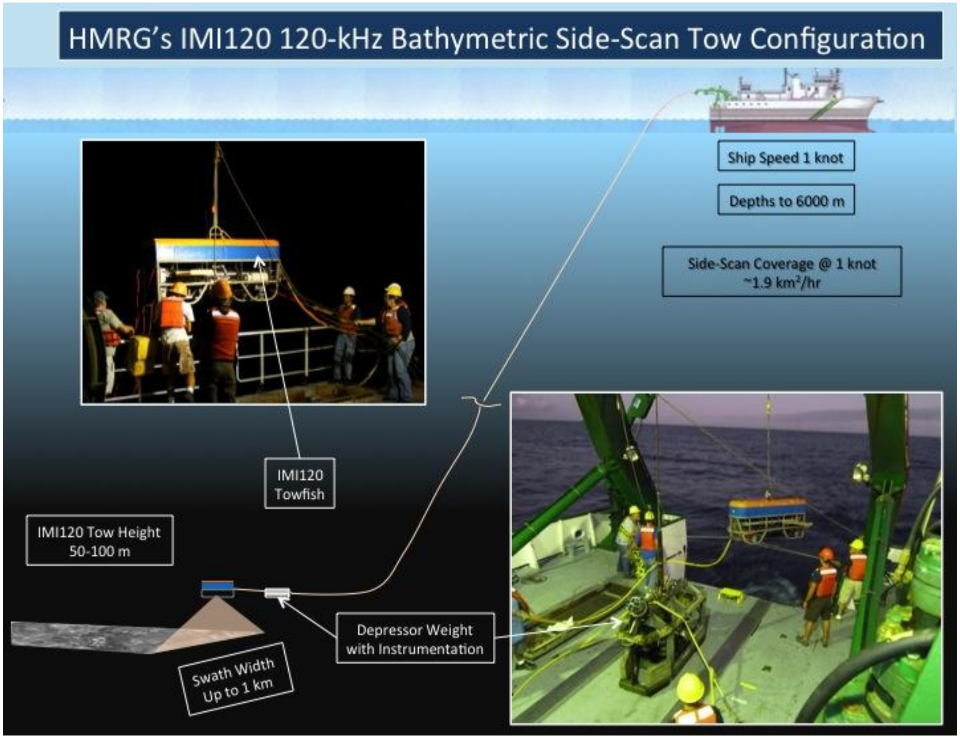


Figure 22: Bathymetric Side-Scan

Development and improvement of underwater technologies, including the use of underwater sensors has greatly enhanced the ability to scan large areas.

The technology to rapidly survey vast areas at various depths is available today and is being used by governments, academia, and businesses worldwide. In addition, the development of sonar technologies has now reached a level where extremely detailed resolution can be achieved utilizing computer enhancement.

One of the best current examples of conducting an underwater survey to detect a suspected toxic chemical munitions underwater dump site is the work that has been achieved by the

Hawaii Undersea Military Assessment (HUMMA) http://www.soest.hawaii.edu under the administration of the University of Hawaii. As a result of research efforts that occurred in 2005 records indicated that in 1944 approximately 16,000 M47A2 toxic chemical bombs containing the Blister Agent (HS) was sea dumped 5-miles off the entrance to Pearl Harbor, the island of Oahu, Hawaii. This location is now situated off one of the most popular beaches in Hawaiian, Waikiki Beach. Based on research data, HUMMA was funded by the U.S. Army, Office of the Deputy Assistant Secretary (Environment, Safety and Occupational Health) to conduct a survey to try to locate the site. Using the research vessel Kilo Moana's hull mounted Kongsberg Simrad, EM1002 multibeam SONAR to collect bathymetry and backscatter data, the HUMMA team established the search perimeter footprint. The IMI-120 Side Scan SONAR was selected was the primary search equipment, due to its ability to detect targets 1-2 m long objects on the seabed at an altitude of 75 meters at a search width 10 times the towfish altitude.

This combination of resolution and area coverage allowed 2.7km of seafloor to be mapped per hour. The data collected allowed for a resolution of 0.25 meters, or approximately one half to one quarter the size of the smallest suspected targets. After completion of the survey utilizing the IMI-120 SONAR, distinct linear patterns were detected that indicated that a disposal action had taken place from a vessel that was in motion. The next phase of the survey was conducted utilizing both ROV,s and their submersibles, Pisces IV and Pisces V. Visual inspection of the debris fields confirmed that identifiable residue of M47A2 Chemical Bombs and conventional munitions. This is an example of current technologies used in the detection of munitions that was dumped at sea over 65 years ago.

Sub-Bottom Imaging Detection Technology

SBI survey are normally conducted in advance of dredging operations to determine the size and number of anomalies prior to dredging operations. SBI swaths are narrow in relation to side-scan or Mags and requires full coverage of a survey area. SBI, is consider expenses when one considers the coverage area of the swath and the time required to post-process data.

The SBI employs three 4.5 kHz to 12.5 kHz LFM chirp projectors with elliptical beam patterns. The projector beam patterns are orientated in such a way as to provide a useable swath width of 5 m at the seafloor and 8 m at full penetration depth, when the transmitter-hydrophones is located at an elevation of 3.5 m ± 0.5 m above the seafloor. This provides swath and proper along-track coverage to minimize unwanted reverberation and meets synthetic aperture processing requirements.

Reflected acoustic signals are captured by the SBI hydrophone array. The SBI hydrophone is a 40-element linear array aligned in the across-track direction with the following dimensions: 3.5m (L) x 0.598m (W) x 0.13m (H).

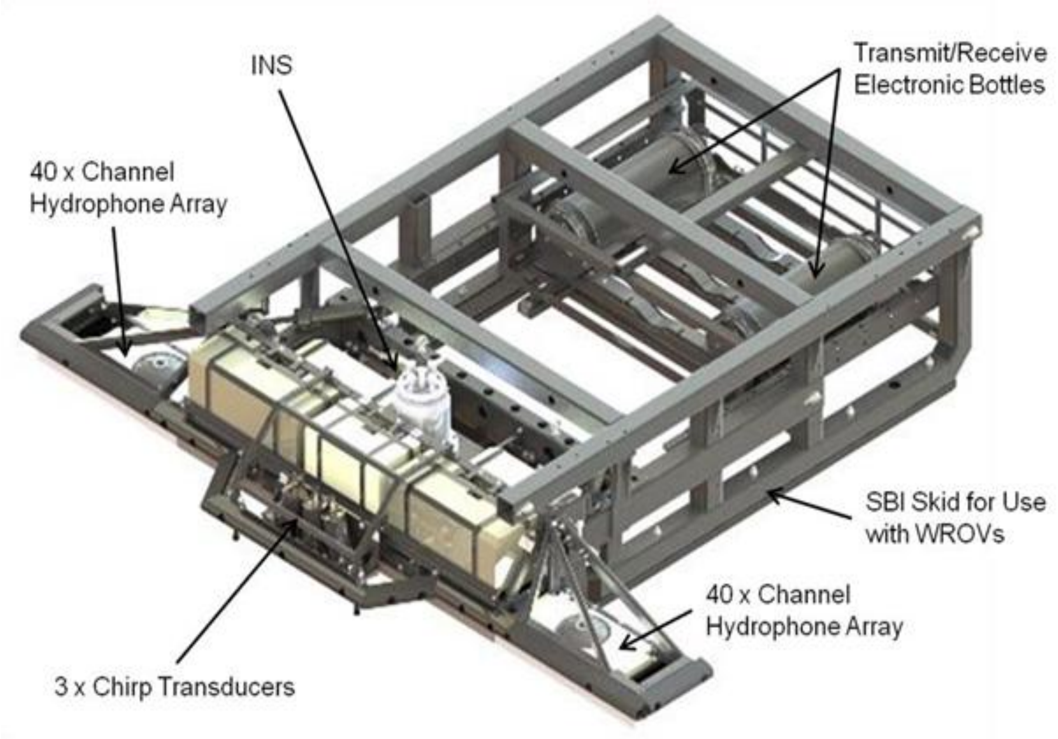


Figure 23: SBI mounted on WROV skid SEA BUND DREDGE CHANNEL FINAL REPORT RPT-08107-1 Page 35 of 38 July 2018

A prerequisite for the effectiveness of the SAS processing are that the relative positions and orientations of the projectors and the hydrophone array must be determined with high precision at all points along the duration of a given aperture window, and the platform must be reasonable stable. This can only be achieved by fixing subsea components to a rigid frame and using a state-of-the-art Inertial Navigation System. PanGeo uses an IXSEA Phins 6000 system (or alternatively a ROVINS system) to achieve the required accuracy. The IXSEA unit mounts on the SBI skid and is attached to the ROV platform together with the other SBI components.

Sonar

Light is absorbed over very short distances in the water environment. In working underwater, the lack of long range vision is a major limiting factor. In the early days of underwater work, performed manually, limited vision was not as significant because the diver could not move from one place to another very quickly. As robotics and instrumental intervention arrived at the worksite, the need to extend our vision became more vital. This becomes even more important because with our remote presence we can move more quickly from one place to another.

Figure 24: IMAGENEX Technology Corp Sonar

To meet the demands of "seeing" further underwater, engineers have turned away from the visible light spectrum and to another form of transmittable energy underwater: sound. Sound is also attenuated in the dense water environment, but not over as short a distance as light. Although the resolution of acoustic imaging does not approach optics, it does provide a remarkable extension of our vision, as the images of the aircraft and collapsed bridge in the figures on this page show.

Those working underwater, including oceanographers, marine geologists, and ROV Pilots now depend heavily on sound energy to transform the things we cannot see underwater into numbers, graphs, and pictures. The ROV pilot in particular requires that the imaging sonar provide him with accurate and quickly updated images. The instruments that transmit and receive these sound pulses have become sophisticated and more accurate in the past few decades.

Underwater, sound transmission is limited. This is most notable in useable ranges. High-frequency sound energy is greatly reduced by seawater. Low-frequency sound energy is reduced at a much lesser rate. For instance, a sound pulse of 50 Hertz can be transmitted many thousands of kilometers in the ocean, but a pulse of 300 kHz, a common imaging sonar frequency, can be transmitted less than 1,000 meters.

As applied to underwater vehicles, sonar systems in use today include mapping and collision avoidance types. Side scan sonar transducers can be mounted on the sides of a vehicle, such as the one shown to the right, to provide a "map" of the seafloor. An advantage of side looking sonar on an ROV is that a long-range image can be provided out to the side of the vehicle's track. One disadvantage of side scan on a vehicle is that, while vehicles can be flown at low altitude along the seafloor, the side scan requires some amount of altitude in order to gain the necessary range. This problem is not new to the combination of long range acoustic and short-range optical imaging underwater. It is not always possible to fully utilize both simultaneously.

Almost every medium and large vehicle does utilize, however, a forward-looking sonar for navigation, collision avoidance and target delineation. These sonars are most often rotary sonars, commonly known as scanning sonar, such as the MS 900 scanning sonar by Kongsberg Simrad shown to the left. They consist of a transducer head, which rotates and is mounted on an electronics bottle. Common frequencies in these units range from about 300 kHz to 600 kHz and above. Again, the tradeoff between the higher resolution of the high frequency and the longer range of the low frequency comes into play. A vehicle may have more than one rotary scan sonar mounted on it. Two frequencies on two sonar heads working simultaneously, for example, will give a pilot a rapid informational update for targets and terrain on both high resolution and long range.

The fact that towed side scan sonars "fly" high above their targets gives them their ability to observe objects, often through the "shadows" cast by the sonar beam. This is shown graphically in the figure of the ship image to the right. Today, color monitors and digital processing enhance the sonar operator’s ability to identify targets.

Synthetic Aperture Sonar (SAS)

The principle of synthetic aperture sonar is to move a sonar along a line and illuminate the same spot on the seafloor with several pings. This produces a synthetic array equal to the distance travelled. By coherent reorganization of the data from all the pings, a synthetic aperture image is produced with improved along-track resolution.

SAS processing have the potential to improve the resolution by one order of magnitude compared to conventional side scan sonars.

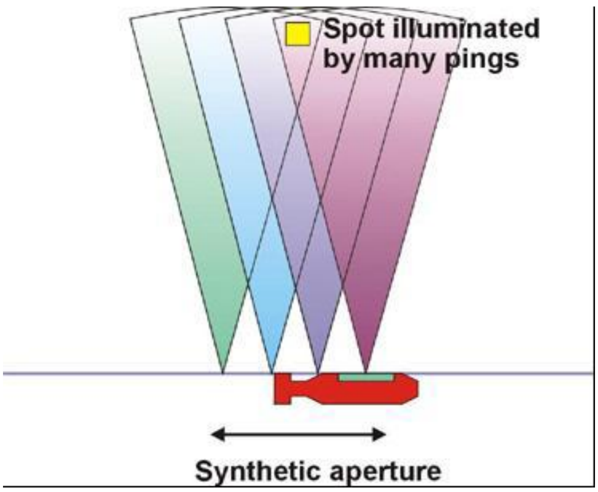


Figure 25: Principle of SAS

The advent of AUVs, and their growing application in the marine research and undersea warfare areas, heralds the entry for SAS into the oceanographic marketplace. AUVs require small payloads for low-power consumption and requirements of form, fit and function. The high-resolution mapping capabilities of small SAS sonars are well-suited for AUVs, with missions that encompass wide-area seafloor surveillance. As these autonomous systems must traverse long distances with limited contact with the surface, they are typically engineered with navigation suites that can be used for the precise navigation requirements of SAS. Furthermore, the slow speeds of AUVs (typically one to five knots) are well-suited to the half-array displacement limitations for synthetic aperture processing.

Magnetometers

Magnetometry is a reliable, proven technology for detecting ferrous items. Magnetometers have been widely used in Europe for detection of underwater munitions. Magnetometry consists of a passive sensor that measures a magnetic field.

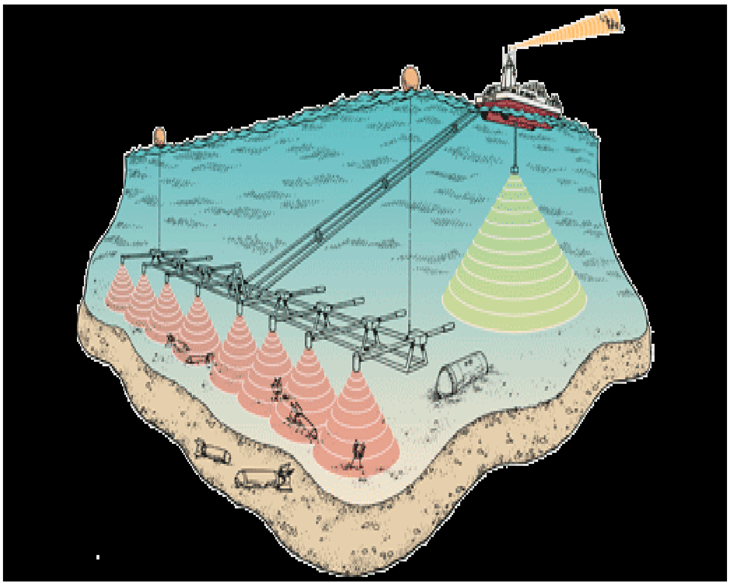


Figure 26: Use of Magnetometers

Magnetometers detect distortions in the magnetic field caused by ferrous objects.

Magnetometer has the ability to detect ferrous items to greater depths than can be achieved by other systems and can identify small anomalies because of the instrument's high levels of sensitivity. Magnetometers are also sensitive to many iron-bearing minerals which affect the detection probability by creating false positives and masking signals from munitions. This affects their utility in volcanic areas such as Hawaii. The two most common magnetometry systems used to detect buried munitions are cesium vapor or fluxgate. Cesium vapor magnetometers measure the magnitude of a magnetic field. These systems produce digital system output. The fluxgate systems measure the relative intensity of the gradient in the Earth's magnetic field. These systems are inexpensive, reliable, and rugged and have low energy consumption. Magnetometers can be deployed on virtually any platform. However, the platform must have been designed with a minimum amount of ferrous materials which would interfere with detection. Another advantage of a magnetometer is that it can detect items that are buried beneath layers of mud and sand. This is beneficial when trying to locate ferrous items of ordnance that has been dumped at sea and has settled to the sea bottom under layers of muck.

Data Fuzing: Sonar and Magnetometer Data

Data Fuzing is the combining of two separate sets of data, from dissimilar sources that are taken simultaneously. Example would be sonar data and magnetometer data collected during a wide area survey. The collected data from the two sources is then processed utilizing computer software. The resulting data produces an enhanced graph display of the surveyed area. The use of this type of technology is widespread in the surface UXO community. For example, Terrance P. Long, President, Wentworth Environmental Inc., (previous) and Thomas deWilde, Geophysicist, aDede www.ADEDE.com have combined a Iver2 Autonomous Underwater Vehicle (AUV) equipped with Side-Scan Sonar (SSS) technology and a marine Overhauser magnetometry. They have conducted a survey on Lake Ontario, near Toronto, ON, Canada, and have proven that this method is far more reliable than regular ship towed surveys utilizing the two separate technologies.Two pipelines and a lost anchor could easily be recognized with the combined results of the magnetometer and the SSS. On top of this, deviations from survey lines are far smaller and less likely than in regular towed surveys, allowing surveys with a denser grid to be performed in rougher waters, significantly increasing survey resolution.

Underwater Cameras

The use of camera systems underwater can be used to enhance the capabilities of both divers and remote systems such as ROV’s and AUV’s. Their primary use is in the identification of items that have been located underwater. In shallow depths they can be used to limit the amount of time divers spend on the bottom investigating anomalies. A simple underwater drop camera can be used to select potential items for further investigation. Underwater mini-rovs exist today that are built around camera systems that add the capability of remote control and movement to assist in positioning camera systems to insure an adequate picture for the viewer. In shallow water where the water is clear visibility is not a real issue. As the depth increases so do the problems associated with camera systems, at approximately 100-feet the visual light spectrum is so degraded cameras become useless without support lighting. Modern day lighting systems can solve a part of the problem but, even the use of powerful external lights cannot solve the other problem that exists, that of turbidity. A majority of underwater operations involve conditions where sediment is suspended in the water around the work site. In these cases where a diver is involved it becomes a matter of touch and feel. Where cameras are useful is on ROVs and AUV’s that by their actions do not disturb the surrounding environment. When working at depths were divers cannot reach safely, cameras are the only method of identifying those items found. Older monochromatic cameras were difficult to use at deep depths. The older video cameras also had problems focusing and providing a clear picture for the viewer. With the advent of digital cameras and computer assisted software some of these problems are minimized. Newer systems being developed and used today can increase the clarity and resolution enormously. In the picture below an AUV flew over a ROV which was at a depth of approximately 900 meters. The close-up shots taken by the AUV’s camera show that it can zoom in close enough to see the antennae on a crab resting on the top of the RV.

Environmental Sampling (and various work required sub-surface)

Additionally, equipment used to work in intrinsically inhospitable underwater conditions include: **manipulators** (remotely manipulated mechanical arms or teleoperation) of which their designs have improved dramatically over the years, integrating effective ergonomics, power and control. High resolution digital cameras that increase the clarity and resolution of objects enormously and the use of remote systems (ROVs and AUVs).

The most basic remote manipulator systems contain only an operator-input device and a jointed manipulator arm. More sophisticated systems also contain control electronics. The tip of the manipulator arm is attached to a tool (such as a pair of jaws, a drill, or a pair of snips) used to perform the required task. A wide variety of manipulator types have evolved to cover a very broad range of subsea applications. These applications range from simple tasks, such as grasping a lift line, to more complex ones, such as plugging and unplugging electrical and hydraulic connectors. When selecting a manipulator, it is important to choose the simplest possible type that can accomplish the task in a reasonable time. In the offshore environment, complexity can generate problems with reliability, operation, and maintenance.

The choice and integration of a manipulator system is complex, and the vehicle designer should consider the following: number and types required, their location, required control type (rate, spatially correspondent, force feedback), lift, maximum (and minimum) reach, and camera locations. Remember, if you can't see it, you can't manipulate it. Manipulator arms can provide multiple degrees of freedom of movement

Figure 27: Manipulator Arm Example

Manipulator designs have improved dramatically over the years, integrating effective ergonomics along with power, dexterity and control. They have become easier to operate and maintain and have incorporated space-age technologies that have increased their reliability. Manipulators can be found in various configurations, degrees of freedom, and end uses are available in manipulators that are on the market today such as the Orion 7-function manipulator, developed by Schilling Robotics of Alstom Automation.

The future will see computer-aided teleoperation that will allow automatically detect potential collisions, move the slave arm directly to an object or along a pre-defined curve, and record manipulator movement paths for later review or playback.

Computer aided control will allow the operator to work with "virtual cameras" that display multiple views of an object from any camera location or angle, along with the ability to pan around the object, or zoom in and out. By creating a viewing site at the end of the arm, the operator will even get a "tool's-eye view" of the task being performed.

As we have seen underwater vehicles can be fitted with various tools such as cameras for still pictures, HD video, side scan sonar, magnetometer (MAG), multi beam and sub bottom profilers. Underwater vehicles can also be fitted with environmental sensors for bathymetry and water column surveys' including contaminates. ROV's can be fitted with robotic arms for munitions handling and sensors for investigation. AUV's are designed to navigate over large distances and hover for extended periods of time in the water untendered over munitions. Geophysical samples or anomalies can be taken and downloaded into an on-board computer-integrated system that includes geographical coordinates and the precise physical characteristics of any number (e.g. thousands) of objects. The anomalies can be mapped then reacquired and addressed at a later date for investigation or remedial action by a diver or underwater vehicle.

A part of the environmental sampling process is a risk analysis of the condition of the munitions that has been found. This analysis will dictate the remediation and disposal procedures that will be used. The first and foremost is the determination if the items contain armed or partially armed fuze(s). The secondary and more common issue concerns the structural integrity of each item to be recovered.

Items containing armed or partially armed fuze(s) will require (if possible) to be rendered safe. If that is not possible then an alternative disposal method(s) may have to be considered.

Alternative methods for reducing the exposure to munitions that are located on the sea floor include both active and passive steps.

Active steps involve reducing or eliminating the potential exposure to the munitions. This could be accomplished by various engineering options that range from laying dredge material such as sand on top of the munitions to the established of an island on top of an entire area. The Belgium Government conducted a study regarding the discovery of WWI chemical munitions that were disposed of off their coast, north of the town of Zeebrugge. Because of the shallow nature of the area and the close proximity of the shoreline the Belgium government was concerned and funded a report containing an evaluation of this site.

Four potential engineering options were discussed in the report.

The first option would be the construction of a cover on top of the munitions, consisting of sediments, such as sand and gravel. The study suggested that a minimum of 5-feet of sediment would be needed to provide a safe cover. To utilize this method successfully the area must not have high erosion rates due to tidal currents or waves. The use of this process would also require constant monitoring to insure items do not become exposed.

The second option that was investigated was the use of stone/concrete riprap to cover the 5-foot layer of sediment. The design of this option would entail multiple layers of rip-rap starting with smaller diameter material and building to larger material. The establishment of a cover on top of a sediment cover will prevent erosion from occurring and would provide protection from ship anchors. Monitoring would still be required but, not as frequently as with just a sediment cover.

The third option involves the construction of a Breakwater on the seaward side where the munitions are located at. The idea behind this was that sediment would build behind the breakwaters to cover the munitions. Utilizing this process a constant layer of sediment is deposited on the munitions.

The last option involves the construction of an island over the entire area that munitions are located. This technology approach is being used worldwide to reclaim land and involves a massive engineering effort.

Passive measures, while are less costly requires that people follow established guidelines. The simplest of passive measures would be the establishment of restricted areas where recreational would be prohibited and strict controls placed on commercial usage where suspected chemical munitions are located at. In order for this process to be successful, it will require that the boundaries for all sea disposal locations be identified and mapped.

Items that have structural integrity problems from corrosion or from internal design is a very important point to consider.

Passive Samplers

NATO Science for Peace and Security (SPS) MODUM Program, selected Bedford Basin for Sea Dumped Chemical Weapons Summer School, to test passive samplers in 2015 based on the region's history with the world's largest non-nuclear explosion in Halifax Harbour in 1917 and the Bedford Magazine Explosion in 1946.
Passive sampling is quickly providing itself, as a new and emerging technology as a rapid and cheap means for small and large areas sampling of the seafloor and water columns for the remains of warfare agents. Samplers can be easily deployed and recovered by an ROV and

recovery systems can be employed by AUV to recover samples.

Sampling logistics, normally to hit target concentration, you'd have to take large volume water samples. With the polymers, you have manageable sampling logistics. The polymers used have a high affinity for the nitrogen containing conventional munitions TNT and RDX, as well as their various breakdown products.

Figure 28: Deploying a Passive Sampler over Projectiles next to Bedford Magazine

The polymer is both polar and apolar, making it useful for this application in particular. This means that they can be placed in the environment, and allowed to passively sample with relatively short deployment times. 48 hours is considered a safe minimum for acquiring meaningful quantification.
The quantification is currently ongoing. These compounds haven't been quantified in this system. These must be extracted in a laboratory setting and quantified utilizing GC ECD (Gas chromatograph with Electron Capture Detector). This allows for the quantification of the

Figure29: IDUM Photo Grab Samplers, NATO SPS MODUM Summer School

parent compounds as well as their degradation products, such as MNX, DNX, TNX for RDX, as well as 2 Amino and 4 Amino DNT, which are metabolic degradation products of TNT.

3. Limitation of certain actions

3.1. Description

Limiting certain actions at sea is a management strategy that leaves the conventional and chemical weapons undisturbed on the seafloor but restricts human activities and economic development in the area so as to limit the risk of exposure. These limiting actions could include: fishing, navigation, tourist activities and construction.

A wide variety of scientific literature suggests that leaving munitions undisturbed is a safer option than attempting to recover and destroy them by some other method (Beddington and Kinloch, 2005). However, as more scientific studies are conducted about the toxicity of underwater munitions and as more technologies are developed to allow non-state actors to recover ordnance from the seabed, this strategy may become less viable in the future.

3.2. Benefits and Risks

Limiting certain actions at sea is a management strategy that conforms to consensus opinions about underwater munitions within the scientific community. Leaving conventional and chemical weapons undisturbed on the seafloor is a safer option than attempting to recover and destroy them by some other method (CITE, ICL page 47). Yet in order to ensure they remain undisturbed there is a need to limit economic and leisure activities in the general vicinities of dumpsites.

Limiting economic activity will affect offshore construction projects involving renewable energy or oil and gas pipelines, as well as transportation infrastructure development. However, limiting actions in dumping areas, such as Bornholm will primarily affect fisheries. In the early 1990s, restrictions around Bornholm Island were put in place and this corresponded to a decrease in the number of reported incidents. Although there are still gaps in the reporting system and many other contributing environmental factors that explain the decreasing totals (such as better technologies and changes in the abundance of fish), restricting fishing is a useful preventative measure.

Limitation of economic activity can be tailored to the specific risk, nature of the activity and local circumstances. For example, activities can take place on the sea bottom or in shallow waters. Trawl fishery runs a higher risk of disturbing munitions on the seabed, as nets are dragged in the deep waters. Construction work (e.g. for windmills) on the sea inevitably interferes with the seabed. In comparison, pipelines and cables are closer to the sea level and therefore running less risk of unintended exposure of toxic materials. Different limitations can be imposed on the various economic activities. Fisheries can be forbidden from anchoring or partaking in trawl fishing, rather than forbidding navigation in the area altogether.

Limiting public access to shorelines or specific areas at sea protects public safety. This is especially the case for tourists and beach-goers, who face the direct risk of encountering sea-dumped munitions in the form of white phosphorus. Although raising public awareness in the form of leaflets and hot spots can be sufficient in some cases, there are instances in which the complete closure of parts of the beach is necessary to guarantee one's safety. By limiting beach-goers and recreational divers' access to these parts, local governments or responsible organizations can further analyse the presence of these materials and assess the risks to humans (and the marine environment) without negatively affecting people's probability of getting in touch with these harmful materials (Knobloch et al., 2013).

The limitations of this management strategy apply to all scenarios of dump sites as long as they are not actively doing environmental harm; however, include the associated risks of leaving munitions to degrade and corrode on the seafloor, as well as the potential of fishermen, private companies, and tourists ignoring the restrictions and warnings altogether. This management strategy potentially reduces the risks of contact but it does not eliminate it.

3.3. Limitations for the Baltic Sea Area

Due to the proximity of the EEZs, the limiting of certain actions such as having an anchoring ban or limiting sea harvesting may severely burden multi-national agencies tasked to police activities and further burden resources that could be more effectively used in other management options. Furthermore, this option may also infringe on marine navigational and sea harvesting rights unless the issue of safety or severe environmental impacts are superseding such rights are clearly defined.

The limitations of this management strategy include the associated risks of leaving munitions to degrade and corrode on the seafloor, as well as the potential of fishermen, private companies, and tourists ignoring the restrictions and warnings altogether. This management strategy potentially reduces the risks of contact, but it does not eliminate it. Moreover, there is also the added complication of ensuring that stakeholders from all countries are aware of the restrictions and abide by them. Laws in one country may not be consistently applied by other countries. Gaps in reporting systems may also complicate this management strategy.

When a limitation of certain activity is pursued, legal difficulties and limitations are a burden to an effective and lawful policy. As well as the problem posed by the enforcement gap between national laws and international waters, unilateral limitations by countries are unattractive because this would disadvantage the own industry while other national industries profit from the exit. A disadvantage for ships under one flag can also be construed publicly as an unfair advantage for ships of other states, which could lead to political backlash from producers and consumers.

Moreover, unilateral limitations run afoul of the EU's Common Market principles, where harmonization of rules and the absence of economic barriers among member states take precedence. A unilateral anchoring ban for ships of all nationalities, for example, has the effect of a trade barrier towards other countries. These asymmetric policy effects were rendered illegal by the Court of Justice of the European Union in the seminal Cassis de Dijon case, despite the motivation of protection of health and consumers (Garret, 1995). Economic limitations therefore should be pursued on a supranational level in the European Union.

From a logistical point of view, monitoring adherence to limitations on activities becomes more difficult in distant and international waters. This is especially important for remote munitions dumping sites. Besides the legal limitations posed by free navigation rights in international waters, governments cannot easily inspect, check or control actions by those responsible on the sea. The low risk of detection or enforcement ensures there is a low incentive to adhere to the rules.

In the Baltic Sea, nine countries perform fishing activities. A high number of large vessels come from Poland, Sweden and Denmark. Fishing landings have declined since mid-1990's, but fishing landings have accounted above 600.000 tonnes in the Baltic Sea (ICES, 2017). Limiting economic activities will therefore have a great impact on fishing. Swedish marine tourism in the Baltic Sea accounts for 1,4 million Swedes every year partaking in recreational fishing, producing 30.000 jobs and 15 billion Swedish kronor (Baltic Sea 2020, 2018).

The costs associated with limiting activities instead of handling the source of the threat should also be considered. Presence of munitions and their toxicological properties have a great impact on fish populations themselves, therefore threatening the livelihoods of fisheries. For example, mustard gas has carcinogenic properties. Fish spawn in mustard gas also have damaged DNA, leading to a risk of cancer permanently present in their genetics. This brings political consequences and questions of responsibility with it. Limiting economic activities therefore disregards other aspects beside the economic perspective, like ecology, politics.

Therefore, the limitations of this management strategy include the associated risks of leaving munitions to degrade and corrode on the seafloor, as well as the potential of fishermen, private companies, and tourists ignoring the restrictions and warnings altogether. This management strategy potentially reduces the risks of contact but it does not eliminate it but rather may perpetuate it. Moreover, there is also the added complication of ensuring that stakeholders from all countries are aware of the restrictions and abide by them. Especially in the mult-national Baltic, laws in one country may not be consistently applied by other countries. Gaps in consistent and effective surveillance and reporting systems may also complicate this management strategy by overburdening resources.

3.4. Legal limitations, Test Approaches for Remediation

As described above, laws or regulations may not be consistently applied and enforcement would be problematic and a burden on various agencies to ensure compliance. As with other strategies such as no action, and monitoring, legal limitations could also mean that this strategy does not pass the test of due diligence thereby the possibility of litigation for damages (physical or economic). Limiting actions such as fishing, recreation, construction or navigation need to be coordinated with the Maritime Spatial Planning as per the EU Directive 2014/89/EU establishing a framework for maritime spatial planning.

3.5. Technological Availabilities of Limiting Certain Actions

While Limitation of Certain Actions is primarily a policy and legal based management strategy, technology can be augmentative in enforcement and assistance. Comparable to No

Action, the dissemination of information on munition sites and the required course of action is essential to prevent civil or commercial activities from incurring harm. However, with this management strategy activities are pre-emptively limited or forbidden.

Another application areas besides the dissemination of information, is the enforcement and monitoring of economic activities taking place. Around high-risk dumping locales, vehicles and constructors can be required to monitor their location (using GPS or other sea-navigation technologies) and send this information to a central authority. For enforcement, fisheries for example could be required to determine their location before they release deep trawls.

4. Neutralization at sea

4.1. Description

Neutralization at sea nullifies the contamination or potential disruptions caused by underwater munitions, usually without relocating the objects or hazards. This could involve concrete encasements or the introduction of new technologies or substances that will counteract the contamination. The choice between neutralization and other risk-averting management strategies depends on the result achieved per cost.

4.2. Benefits and Risks

These neutralization methods, such as the covering of deposits or the construction of an enclosure around the weapons site, prevent the surrounding waters being contaminated by toxic chemicals released by deposits. Enclosures seal off the external waters from the contaminated waters or leakages due to deterioration. Wreckages containing weapons can either be sealed off completely or selectively for exposed areas. The required construction depends on the current state of the wreckage, and the rate of deterioration of its material.

Constructions are susceptible to the stability of the seabed and ground shifts, as well as the salinity of the surrounding water. Currents, water temperature, and anthropogenic activities should be considered when deliberating the merits of constructing an enclosure. It should also be noted that neutralization is not a permanent solution to the presence of deposited weapons. Constructions can be costly and require maintenance, with commitments by authorities to provide funding over the long term. Moreover, concrete (which has been favoured when dumping radioactive waste or when relocating Tabrun-filled munitions) deteriorates in seawater.

For chemical munitions the drilling approach could be used. The drilling approach involves creating a small-diameter hole in munitions casings and using suction to draw the munitions constituents into a container that can be safely recovered at the ocean surface or on shore. An advantage of this approach is that can be environmentally safer; for example, it would have less impact on biota that had attached itself to the munitions casing in a coral reef.

Disadvantages are that this approach can be time-consuming and that there is the potential for leakage of toxins once the material has been removed from inside munitions casings. Efforts are undertaken to adapt a drilling approach for conventional munition, by using water jets to break solid explosives into particles small enough to suction (ROBEMM project, http://www.munitionsraeumung-meer.de/en/national-research/robemm/). Encasing MEC in concrete can be a faster and more cost-effective solution, but depending on the distribution of munitions and nearby animals, it can have a significant, negative impact on the environment.

In-situ methods include hydrolysis of munitions constituents in underwater domes and various sediment capping options (Duursma and Surikov, 1999), which could either transform toxicants into less toxic compounds, or separate them from the bottom water for long enough to be buried by sediment layers or for the natural depuration processes to complete. The disadvantage of the in-situ approach is the elimination of selected sea bottom areas from the ecosystem, in terms of habitat, and other ecosystem roles and services they normally provide. In-situ methods were successfully demonstrated in the Black Sea, where post Soviet chemical munitions were encased by concrete sediment capping (Korendovych, 2012).

4.3. Limitations for the Baltic Sea Area

As implacements or other constructions can be destroyed by nets, boats, or natural processes especially on the relatively shallow waters of the Baltic, the neutralization methods may require ongoing monitoring and maintenance. Information and procedures for fisheries and other users must also be provided and identified on maps.

The feasibility of neutralization depends on the depth of the prospective weapons dumping site and on the hydrodynamic activity at the dump sites as deeper locations and the occurrences of hydrodynamic forces increase costs and efforts. Constructions on the sea may also be weakened or unable to be built because sediment capping with sand or silica may easily dissipate. If the area is hydrodynamically active (i.e. strong and frequent streams), sediments can also be washed away, therefore weakening or rendering inoperative the construction.

4.4. Legal limitations, Test Approaches for Remediation

The legal limitations for this strategy would be similar to monitoring and limitations of certain strategies because continuous monitoring would be necessary to ensure construction viability and stability with an appropriate due diligence test. In addition, because the constructions require enforcement of limiting certain activities, this would require continuous enforcement and be in contravention of certain countries right not to limit certain activities.

4.5. Technological description of Neutralization at Sea

Technologies that enable the removal of risks by dumped munitions, while leaving them unattended are central in Neutralization at Sea.

To prevent leakage or spread of toxic chemicals or dangerous materials, watertight containers can be used. These watertight containers are disposable and able to withstand the sea floor pressure. They provide containment and make sure the munition cannot leak and damage the environment.

Once on the surface, the container with the munitions can eventually be fed to the static detonation chamber (see Recovery and Destruction), such as the SDC 1200 CM system. This environmentally acceptable technology causes the materials to decompose, destroying the chemical agent and the explosive at the same time. Without the feeding to a SDC, munitions in watertight containers decompose slowly at a natural rate.

The technological availability of the Neutralization at Sea management option are integrated in section 6 - Recovery and Destruction.

5. Detonation in In SITU

5.1. Description

Controlled detonations of chemical or conventional munitions destroys the dangers without having to invest significant money or labour in recovery, relocation, or destruction. This strategy is a viable option for munitions that are too dangerous to move or found in an area where human exposure is likely to occur or the risks to economic activity are high. However, it is also accompanied by some serious energetic risks to local infrastructure, fish populations, and can spread contamination over a wider area.

5.2. Benefits and Risks

Most common clearance method of dumped conventional munition is in situ detonation with a donor charge. Such clearance is usually assisted with mitigation strategy for protection of marine biota, but those are limited in many cases to noise mitigation measures, as well as detonation of a scaring charge, to remove sensitive life from vicinity. This practice is commonly adopted by many naval forces worldwide, which does not necessarily mean that it is environmentally friendly.

During in situ detonation, both toxins still contained in munitions and those included in nearby sediments are delivered to the water column and may contaminate large areas and could be ultimately incorporated by marine organisms. Adding explosives to cause detonation creates a greater environmental impact. Earlier studies show that during blasting significant TNT and RDX residues are observed in blasting site. (Pennington et al., 2008). Especially low order detonations preferred for clearance can distribute large pieces of UXO in the environment (Juhasz and Naidu, 2007)

For example, in a Germany case: 930,000 sea mines, each has 630 kilograms. Munitions break up into hunks, being released in a shorter amount of time than by any other method.

The choice of this management strategy should take the local ecosystem into consideration, including destructive force and products of detonated weapons, depending on the explosive agent. Adverse effects include small-scale loss of fishing and marine life and possible release of toxic end products. Detonation in situ is also not an option when infrastructure and gas pipes are in close proximity to the dump site. In light of additional growing economic activity for wind farms and communications, prior consideration of detonation in situ and other management strategies before the start of such projects is prudent.

When constructing the Nord Stream pipeline across the Baltic, the company encountered many chemical and conventional munitions on the seabed. In some instances, consultations with local authorities determined it was best to perform no action, such as with the five chemical munitions found in Danish waters. As of June 2010, Nord Stream had cleared over 100 munitions from Russian, Finnish, Swedish, and German waters because these objects posed a danger to the pipeline. When detonating the munitions, Nord Stream developed a comprehensive plan and procedures that included several steps to assess the technical elements of performing the task and to mitigate the environmental impact on marine life. Through a subcontractor, Nord Stream consulted with marine biologists, monitored for marine mammals, surveyed fish populations, risk models were conducted, and prior to the detonations fish scaring charges and seal scrammers were used to displace fish and marine mammals (Nord Stream, 2010).

5.3. Limitations for the Baltic Sea Area

Unwanted release of and contact by toxic materials by detonation on site in the Baltic Sea is of a higher concern, due to the shallower waters and closer proximity to coastlines. As ordinance lies closer, surface water action during the controlled detonation process runs the risk of inadvertently triggering detonation. Hart (2000) proposes underwater platforms from a distance from the operation ship and on a low depth. However, this would be difficult in the Baltic shallow waters. Locations with a high concentration of economic infrastructure (energy, communications) also exclude the use of detonation in situ.

The detonation of weapons can also interfere with marine life in the wide area because of sonic effects. Peng, Zhao and Liu (2015) have shown that anthropogenic activities in the sea has resulted in emigration, mass strandings, decreased growth and increased metabolism for different species of sea life. Noise possibly interferes with echolocation, communication and stress responses. One of the sources tested was seismic airguns. Therefore, detonation in situ could have comparable effects on marine life and have long term economic and marine life including marine mammals, various fish, waterbirds, population consequences and in direct contravention of HELCOM recommendations.

5.4. Legal limitations, Test Approaches for Remediation

This strategy runs the risk of further environmental damage in contravention of HELCOM recommendations, and although most current treaties do not specifically address the concern of underwater munitions prior to January 1985, The 1972 United Nations Conference on the Human Environment in Stockholm produced a "Declaration of the Human Environment", which stated as a general principal:

> *States shall take all possible steps to prevent pollution of seas by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.*

In addition, the 1982 United Nations Convention on the Law of the Seas (UNCLOS) provides for regulations and guidelines aimed at protecting the environment and the management of marine natural resources.

Therefore, the above (voluntary) declaration and convention would preclude the this strategy unless any environmental concerns were entirely mitigated.

5.5. Technological description of Detonation in SITU

Detonation of dumped munitions on location will require the use of external fuzing or ignition technologies, as these are deemed unreliable on deteriorated munitions itself. Additionally, autonomous vehicles (see Monitoring) would be used to limit human and physical contact with potentially sensitive weapons and to prevent loss if uncontrolled detonation occurs as a result. Alternatively, a less controlled application of detonation is the use of modern explosives to effect a chain reaction of the dumped munitions.

5.6. Technological availability of Detonation in SITU

Research conducted by the Russian financial and industrial company "Ecotransenergomash", the designer-shipbuilders of St. Petersburg, Severodvinsk, Nizhny Novgorod and the designers of the Russian Airspace Complex has produced a promising method for transforming underwater chemical dumps by chemical, plasma-chemical and electro-discharge methods into soluble and insoluble components and for the transport of the soluble components in containers to a mother ship for treatment on-board.

Technical feasibility

1. Technically it is not complicated to erect a two-layered dome 50-70 metres high with a diameter of about 200 metres and consisting of an inflatable membrane and a stabilising concrete ring. Modern shipbuilding and aerospace industries are highly developed and capable of producing durable hermetic domes of the necessary size.

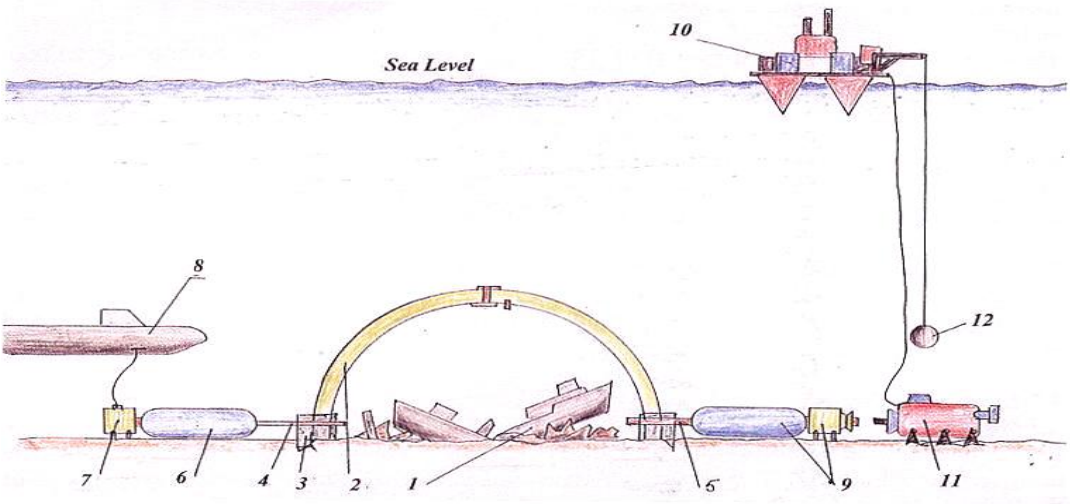
2. The technology of processing under a dome is based on a similar kind of experience in surface conditions for extracting deposits of gold and uranium. Available chemical engineering facilities can assure the undertaking of such processes in closed volumes above the seabed.

3. Technical systems of pumping and transport are determined by the requirements for absolute ecological safety. In depths up to 100 m, such safety would be ensured by a special pipeline system hermetically joined to a dome. Below 100 m, the employment of an underwater transport tanker would be required.

4. When processing chemical products on mother-ship-factories, the major problem is to produce sufficient power for the treatment of huge water masses, but however complex the techniques may be, the various types of plasma-chemical reactors developed within the last decade can cope with the technology. Substantial studies by physicists and chemists should be conducted simultaneously with the design and creation of the entire complex so that the correct decisions are made.Basic scheme of underwater treatment of leaked CW agents from dumped chemical ammunition is depicted in Figure 30 (Duursma, 1999).

The concept shown in Figure 30 is a two layer dome (2), is erected above a wrecked ship containing a CW cargo or above CW ammunition (1); an inflatable membrane is fixed on the seabed by a concrete ring (3). The dome (2) is equipped with two pipes (4) and (5), through which the input of chemical reagents and plasma-chemical or electro-discharge reactors and the output of products of underwater chemical reactions are affected. Pipe (4) is connected with underwater containers of chemical reactants(6) and a junction (7) is made with an underwater tanker (8), which ensures delivery and replenishment of the chemical reactants. Pipe (5) is similarly connected with a junction (9) for unloading liquid reaction products from under the dome (2) and their transfer to a mother ship (10) for further treatment on board. Depending on the depth, the transfer of liquid products may be carried out either through flexible pipelines connected with the junction (9) or through hermetic inflatable cylinders (12) filled by a special underwater tank-device (11).

Figure 30: Dome Encased Chemical Munition Recovery and Destruction or Detonation in Situ



6. Recovery and Destruction

6.1. Description

The recovery and destruction of conventional and chemical munitions is an essential step in decreasing the amount of underwater munitions. There is plenty of information regarding both the recovery of sea-dumped chemical weapons and the possibilities regarding on- and off-shore treatment. Many organizations, like UXB and DYNASAFE have been involved in munitions recovery operations and/or in the production of different types of transport chambers for both conventional and chemical munitions.

6.2. Benefits and Risks

Recovering munitions from the seafloor is a high-risk operation. Removing conventional or chemical munitions means there is a possibility of damaging the munitions by mechanical actions. This could cause leaks or even the detonation of these munitions. Especially with regard to chemical weapons this would be dangerous, as the Chemical Agent (CA) the munitions are filled with have long-term negative consequences for the environment. Moreover, the destruction of the chemical munitions poses challenges as well. Once found, the chemical agent in the sea is affected by, among other things, the temperature of the water. This can eventually slow the rate at which chemical reactions occur and hamper the necessary concentrations of reagent to destroy the chemical agent.

Other limitations concern the divers that are involved in the recovery of individual items. There are several factors that impede a diver to effectively identify and eventually fuse the individual found on the seabed. After years of lying on the seabed, munitions are usually camouflaged with biological and mineral material. This, combined with the already low visibility of the diver in deep waters and the increased hazard that is created from detonating these individual items, makes an unsafe situation even more dangerous for the worker. However, it must be mentioned that the existence of specialized underwater heavy equipment for both shallow and deep-water operations today significantly increases the safety of divers. In special cases, divers can even be replaced by a variety of technological devices and underwater vehicles, some even capable of operating at depths of 2,500 meters in the ocean.

Recovery and destruction should only be considered if the destruction method involves blast chambers, given that the alternative land-based destruction method involves Open Burning or Open Detonation (OB-OD). Although OB-OD is substantially cheaper to operate, it pollutes surrounding lands with munitions constituents that require further remediation. Controlled detonations and burns have significant environmental and technical challenges related to harmful emissions, soil and groundwater contamination, spatial requirements, hours of operation, noise, and legal restrictions on the practice (Alternatives for the Demilitarization of Conventional Munitions, 2018).

Recovery and Destruction may be the more environmentally long term solution because it removes the problem rather than performing actions of monitoring, limiting actions, neutralization etc. rather than deferring the eventuality of the requirement for this more permanent solution. The investment in this strategy would need to outweigh the costs of having to perform the other strategies over the long term.

6.3. Limitations for the Baltic Sea Area

The recovery and destruction of munitions is a high cost operation, as is the case with the use of Static Detonation Chambers (SDC). There are several requirement that have to be met before sea-dumped chemical weapons can be destroyed. Not only must the threat be great enough in order to justify this kind of effort, but a detailed planning of the operation must be made, as well as a thorough analysis of the total amount of munitions and the development and implementation of a safety plan. These are not only time-expensive, but sufficient budget has to be allocated in order to effectively carry out these efforts.

Large scale projects involving recovery and destruction would benefit from Baltic countries cooperation and coordination. For efficiencies several sites could be chosen for larger scale coordinate efforts. Much activities in Baltic Sea have concentrated on variations of the previous management strategies. In the past there has only been one large-scale recovery effort off the coast of Germany in the late-1950s. The goal was to recover munitions for the scrap metals, which were needed for postwar industrial production. The recovering was done using old torpedo nets, dredges, and electromagnets to collect munitions buried in up to five feet of sand. Between July 1952 and December 1954, one plant scrapped approximately 50,000 tons of ammunition, but an accidental explosion in 1953 demonstrates the hazardous nature of the task. It could only be done in areas with low population density and with certain types of munitions. Today the recovery of scrap metals from munitions is not a viable option because of corrosion and the dangers associated with transporting them from the seabed to the factory.

Due to the proximities of EEZ and a more likelihood of the possibility of centrally funded synergised removal efforts, the Baltic area should employ a larger scale effort from numerous sites involving several different countries for the principal of economy of effort.

6.4. Legal limitations, Test Approaches for Remediation

The legal limitations concerning this strategy would be determining the legal environmental laws and regulations of the country involved in the destruction effort on land. Permits and approvals with likely environmental mitigations would be required.

If the recovery and destruction is implemented at sea, then appropriate approvals for affecting navigation during the project along with safety plans and environmental mitigation plans must be approved by the jurisdiction (s) contracting the work.

6.5. Technological description of Recovery and Destruction

Recovery and destruction is, in essence, a two step process. Technologies are used during the recovery of munitions and the destruction of these recovered munitions; either on the sea or on land.

Technologies that can be used for the recovery of chemical and conventional munitions are Floatation Bags and Dredging. Floatation bags are effective at accurately retrieving munitions, whereas Dredging is a technology used for the removal of large volumes of underwater munitions. Other tools that are effective at the accurate retrieval of munitions are Mechanical Manipulator Arms. These are remotely operated, drastically reducing the risk to operators and divers.

There are several technologies that can be used for the destruction of conventional and chemical munitions. Destruction technologies can be designated by open burning/open detonation (OB/OD) or closed burning/closed detonation (CB/CD), indicating if the reaction takes place in a shared or contained atmosphere. The choice between closed and open systems is important to alleviate environmental impacts resulting from open burning or detonation (National Academies of Sciences, Engineering, and Medicine, 2018, pp. 10-11).

One major category of destruction technologies are static detonation chambers (SDCs). SDCs are closed containers that detonate or slowly deflagrate handled munitions by heating of these containers. SDCs are therefore often considered a CB technology. SDCs are built with an enforced stainless steel hull, separated in loading and detonation chambers. Disintegrated munitions in the SDC chamber are periodically emptied by 180 degree rotation of the detonation, with fragments unloading into a bin. These fragments can afterwards be used as bed for a next detonation round.

Another closed detonation appliance, is the use of Controlled Detonation Chambers (CDCs). These CDCs are considered a CD technology. The munitions are destroyed by placing primer charges on the explosives and detonating them inside chambers that are designed to absorb the force of the blast. They make use of sophisticated filtration systems to remove harmful particulates and residues. The main differentiation of CDCs is the use of these 'donor charges'. Specific types of these CDCs include the DAVINCH and the T-60 systems.

The use of Explosive Destruction Systems is an option as well. EDSs are mobile systems that are mounted on a trailer. They fall within the category of CD technologies. They are used to destroy (explosive) chemical munitions that are deemed unsafe to transport. Specific types of Army EDS's exist, such as the EDS Phase 2 (EDS-2), designed to handle munitions containing up to 4.8 lb TNT-equivalent of explosives.

6.6. Technological availability of Recovery and Destruction

Recovery of munitions is a high risk and high cost operation. During removal, mechanical actions could damage the munitions resulting in a leak or detonation. In the case of Chemical Agent (CA) filled munitions there is the possibility for the release of large quantities of CA. However, recovery is the only action that would provide a permanent reduction in long term risk. Treatment of the CA as it is released to near bottom waters has some severe technological challenges. These include temperatures which slow the rate of chemical reactions and difficulty in maintaining proper reagent concentrations to assure destruction of the CA. This alternative is complicated when different types of CA are present and differing reagent are required.

Containment could be accomplished through placement of an inert covering material to prevent or slow the corrosion of the CWM and release of the CA. It is also possible for the materials used for containment to include a reagent capable of degrading the CA.

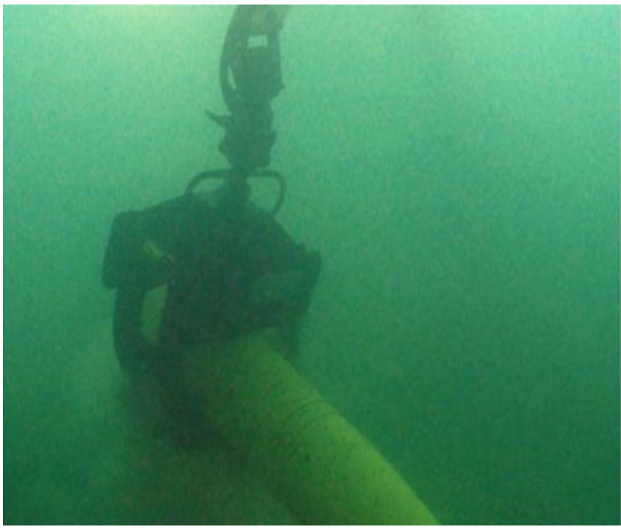
Recovery of individual items has traditionally been conducted by divers. Low visibility, sedimentation, and biological and mineral coatings on munitions makes identification and determining the items' is fuzing and arming status difficult if not impossible. This uncertainty in conjunction with the increased hazard associated with a shockwave from a detonation makes ensuring worker safety a priority. In those cases where CA maybe present or in the case where risks to divers are too great, the use of ROV technology that is currently available must be used. Large scale recovery of underwater munitions has only seldom occurred and has never been conducted for CWM. The only large scale munitions recovery effort known was conducted off the coast of Germany following World War II through the late 1950s. The metals in the ammunition were useful in starting post-war industrial production. Thus, disassembly became a viable alternative to dumping and recovery of previously disposed munitions was started. Immediately following the war, torpedo nets were used for recovery. A variety of devices including electromagnets, dredges and drags were also used. Using the magnets, munitions buried in up to five feet of sand were recovered. The grabs were also effective in recovering buried munitions. The recovery operation was conducted commercial salvage of the metals. This was initially productive but by 1957 only two ships remained in operation. A plant recovering the metals experienced a large explosion in 1953 and ceased accepting certain types of ammunition which was re-disposed. Between July 1952 and December 1954 the plant processed approximately 50,000 tons of ammunition.

Due to environmental conditions which are likely to have affected the items in different ways and the variety of potential fills disposed in the same areas, each item so difficult to handle to the point that each must be treated as unique. Specialists must evaluate each item and determine the most appropriate destruction technique.

Figure 31: Remote Operated Excavator

Today's technology is available for underwater munitions response applications including specialized underwater heavy equipment for shallow and deep water operations. One example is a large remotely operated excavator (ROE) from Norway developed for Oil and Gas that can operate up to a depth of 2,500 meters in the oceans with similar capabilities of underwater vehicles.

Figure 32: UOR Underwater technology



The underwater excavators have the ability to: excavate munitions and other debris from the sea floor; vacuum discarded military munitions (unfuzed) up to 46 cm in diameter; vacuum munitions constituents from the sea floor to a top-side facility or surface vessel for treatment and recycle; relocate munitions from the seafloor to the surface or for disposal; and or bury munitions under the sea floor to an approximate depth of 10-15 meters. technologies involve the use of specialized equipment that is designed to remotely move hazardous items of ordnance.

Underwater Ordnance Recovery, Inc. has developed a remote operated mechanical lifting device that can operate at both shallow and extreme depths. This type of technology coupled with the use of what are called "Lift Bags" can be used in shallow to medium depths to remove munitions from the seabed. The use of lift bag technology has been around for a long time and has provided to be successful by military EOD operations and by commercial underwater salvage divers.

By utilizing a remote handling device to pick-up and move an item of ordnance, it could be then placed remotely in a basket containing a lift bag attached to it. Once the ordnance item is secured in the basket, the lift bag could then be remotely activated and remotely towed to a safe area for disposal.

Dredging

Dredging is another technology that has been in use for a long time and has been used both in the past and is currently being use to remove ordnance from the ocean floor. Many European and Asian UXO Companies have been using this technology to remove munitions from underwater locations worldwide. The U.S. Department of Defense research agency, Environmental Security Technology Certification Program (ESTCP) in a project report, MM-0321, "Dredging Equipment Modifications for Detection and Removal of Ordnance" dated December 2006 identified 15 separate occasions where dredging was used to recover The port of Kokkola is located on Finland's Gulf of Bothnia coast. In 1995, the Finnish Maritime Administration initiated port development projects that included improved access to the channel and land reclamation. During 1997–2001, the depth of the Kokkola channel was increased from 11 m to 13 m , with dredging depths to 15.6 m.

During this operation, the trailer dredge Nautilus had to stop work. While dredging in the inner channel, military munitions were found in the trailer's drag head. Subsequent investigation indicated that the port of Kokkola was a previous transit route for vessels carrying decommissioned ordnance from just after WWII to 1974. A depression located 50 km from the port was apparently designated as a final military munitions disposal site during the period in question. Munitions were also disposed of in the adjacent shipping lane. In addition, this area had been bombed during WWII, causing this area to be subsequently assessed as extremely dangerous because of the potential for finding large unexploded aerial bombs. Dredging operations in the area were delayed while the Finnish Defense Forces and the "Terramare OY" dredging company developed new safety procedures for dredging and for handling the material containing the dredged military munitions. At the same time, it was necessary to determine if unexploded 500-kg aerial bombs existed in the area. Project planning and modifications were scheduled during the autumn of 1997 into the spring of 1998. Changes to the dredging procedure and dredging equipment were subsequently employed. Based on the inability to determine whether a magnetic signature would represent an explosive or non-explosive object, the plan had to consider blast danger relating to the potential for a large aerial bomb to explode during the dredging process. A remote-controlled dredging approach with a mechanical dredge was developed based on the conclusion that the dredge and personnel working on the dredger could not be protected from the explosion of a 500-kg aerial bomb. An operating raft was developed to remotely control the dredge functions from a safe offset distance of up to 500 m. The dredge operator's commands were transferred via radio control from the raft to the dredge. The operator would effectively perform the same actions as if he were on the dredge. Cameras and monitoring equipment were mounted on the dredge to inform the operator (located on the raft) of the dredging parameters and circumstances. Arrays of magnetometers were towed through the area to locate and identify ferrous magnetic signatures. Remote-controlled dredging was carried out at each ferromagnetic signature location of 37 mm or greater; otherwise, normal dredging operations predominated. Dredging was remotely controlled within a 10-m radius of the detection points. The total dredging area was approximately 3.5-km long and 300-m wide. The volume of material (clay and silt) containing military munitions was estimated at 1.2 million m3.

Military munitions found included cartridges, artillery, and grenade launcher rounds, fuzes for artillery projectiles (projectiles ranging from 37 mm to 155 mm in diameter), and aerial bombs of 100 to 500 kg. The ammunition ranged in size from small arms to 0.5 m in length and was normally cylindrical. To dredge in the ammunition-littered region, the dredge Kahmari, a remotely controlled grab dredge with a 5 m3 clamshell, was used. Additionally, the areas surrounding the ammunition-contaminated region were cleared by using a 7 m3 bucket backhoe, the Koura, and a 15 m3 bucket grab dredge, the Meri-Pekka, both of which were manned. For the manned dredging operations, personnel were protected with bulletproof glass and steel safety partitions. The material obtained by remote-controlled dredging was transported to a separate disposal area by a split hull barge with a 300-m3 capacity. Material removal/disposal from the barge was remotely controlled from a tug at a standoff distance of 300 m . The containment basin for final disposal of the material containing unexploded ordnance was 300 m by 500 m. A gravel berm surrounding the basin was constructed with 600,000 m3 of blasted rock to a depth of 10 m. The basin was backfilled with clean earth material after the dredged material was placed in the basin. The material from the surrounding area was transported by manned 600 m3 split-hopper barges to a reclamation site.

Where large quantities of munitions are located underwater, open air detonation and underwater disposal are problematic. In some cases, this may cause more harm to the environment than if they were left in place to slowly decay.

Detonation Chambers

The recovery and destruction of sea-dumped chemical weapons is not only important, it can also be done effectively. Although there are many possible munitions disposal approaches, two that are applicable to both chemical and conventional munitions are the controlled detonation chamber (CDC) systems and the static detonation chamber (SDC) systems. Technology developers have provided several solutions for safe and environmental friendly disposal. Four examples of these types of technology have been reviewed by the U.S. Department of Defense and a report issued by the U.S. Army Board Science and Technology Board describes how each system works:

DAVINCH: (Detonation of Ammunition in a Vacuum-Integrated Chamber) The DAVINCH comprises a double-walled steel vacuum detonation chamber and an off-gas system. The process uses a detonation chamber in which chemical munitions are destroyed. Donor explosives within the near-vacuum chamber are used to detonate and destroy chemical munitions. Applications of the DAVINCH include destruction of recovered chemical munitions in both Kanda Port, Japan and Prelabelled, Belgium.

Figure33: DAVINCH Chamber System

Chemical munitions are placed in the DAVINCH detonation chamber where they are surrounded by donor explosives. The detonation of these donor explosives shatters the munitions, and the shock and heat of the explosion destroys the chemical agent and energetics. Off gasses produced by the detonation are treated by a cold plasma oxidizer, which converts carbon monoxide to carbon dioxide.

Figure34: Projectiles before and after being detonated in DAVINCH

The DAVINCH destroys chemical weapons by using detonation technology. The use of vacuum reduces noise, vibration and blast pressure. The off-gases resulting from agent destruction in the DAVINCH vessel are filtered to remove particulates and, with oxygen from an external supply, are pumped into the cold plasma oxidizer, which oxidizes CO to CO2. Condensate water is then recovered from the exhaust gas; the gas is passed through activated carbon and exhausted to the atmosphere.”

T-60: “The TC-60 has three main components: a detonation chamber, an expansion chamber, and an emissions control system. A munition wrapped in explosive is mounted in the detonation chamber. The floor of the chamber is covered with pea gravel, which absorbs some of the blast energy. Bags containing water are suspended near the projectile to help absorb blast energy and to produce steam, which reacts with agent vapors. Oxygen is added when destroying munitions containing mustard agent. After the explosive is detonated, the gases are vented to an expansion chamber, then to the emissions control system. The off-gas treatment system includes a reactive-bed ceramic filter to remove acidic gases and to collect particles such as soot and dust from the pea gravel. A catalytic oxidation (CATOX) unit oxidizes hydrogen, carbon monoxide, and organic vapors from the gas stream before the stream is vented through a carbon adsorption bed and released to the atmosphere."

SDC 1200 CM: "The static detonation chamber (SDC)is a nearly spherical, armored, high-alloy stainless steel vessel.

Figure 35: SDC 1200 CM System

The vessel is double-walled, with the inner wall considered to be armored. Chemical munitions are placed in a cardboard box or carrier, which is transported to the top of the system. The boxed munitions are fed into the detonation chamber through two sequential loading chambers. The boxed munitions are dropped onto a heated (550°C-600°C) shrapnel (scrap) bed at the bottom of the detonation chamber, resulting in deflagration, detonation, or burning of the munition's explosive fill. The chemical agent in the munitions is thermally destroyed or decomposed due to the high heat in the inner chamber. The off-gas treatment system includes a cyclone for removal of large particulates and a thermal oxidizer/ or flameless thermal oxidizer that converts remaining organic materials to carbon dioxide and water. This is followed by a fast quench system to minimize dioxin and furan formation, acidic and basic (caustic) scrubbers, and an absorber/particulate filter system. If required, NOx can be taken out in relevant DeNox treatment system." The SDC technology has been applied for campaigns in Germany, USA and Japan to destroy old chemical weapons. In Anniston, Alabama, at ANCDF, roughly 2.700 round have been processed with SDC 1200 CM and at the German destruction site for old chemical munitions, Munster, roughly 20.000 pieces of old munitions have been destroyed.

Army EDS: "The U.S. Army's EDSs are trailer-mounted mobile systems originally intended to destroy explosively configured chemical munitions that are deemed unsafe to transport. The

Figure 36: EDS -2 System

system has been used to destroy chemical munitions with or without explosive components. At the heart of the EDS system is an explosion containment vessel.

The EDS Phase 2 (EDS-2) containment vessel is designed to handle munitions containing up to 4.8 lb TNT-equivalent of explosives. The EDS uses explosive shaped charges to access the agent cavity and to destroy any energetics in the munition. After detonation of the shaped charges, reagents appropriate to the agent to be neutralized are pumped into the vessel and the vessel contents are mixed until the treatment goal has been attained. After the concentration of chemical agent falls below the treatment goal, as determined by sampling the contents of the chamber, the liquid waste solution is transferred out of the chamber into a waste drum. The drummed EDS liquid waste is normally treated further at a commercial hazardous waste treatment, storage, and disposal facility."

These systems may need to be adapted to address the specific needs relating to recovered underwater munitions, but they are accepted by regulatory agencies and are already operating at terrestrial sites in the EU, China, Japan, Germany and the United States.

A very good example of this existing technology is Kobe Steel's DAVINCH system that was utilized at the Port of Kanda, Japan where Eighteen chemical munitions were recovered. In 2003, by using a magnetometer, another 500 chemical munitions were discovered. Kobe Steel, Ltd. Designed a process that encased the munition in a container at its found depth and, after the munition was raised to the surface, it was encased in a second container and placed into storage. The storage container with the chemical munition was placed into a controlled detonation chamber where a suitable quantity of explosive was detonated destroying 99 percent of the agent. The remaining scrap was incinerated destroying the remaining 1 percent.Courtesy, International Dialogue on Underwater Munitions, Blast Chamber

Another approach to disposal utilizes thermal process such as a rotary kiln or furnace to burn off the explosive compounds and treat any potential off-gases. Abrasive water jet cutting has been successfully employed to open and empty over one million projectiles without incident. Once the munitions object is cut open with water jet, the filler material is washed out and recycled. Chemical dissolution as well as acid digestion offers additional disposal options. One proven technology has been developed by Planteco Environmental Inc. based in Athens, Georgia www.planteco.com is a neutralization process. They have developed a chemical compound that neutralizes explosives on contact; the residue can be disposed of a non-hazardous waste.

Natural Energy Systems Inc. ("NES")

Natural Energy Systems Inc. ("NES") is in the business of providing 'Waste to Energy' and 'Renewable Energy' process solutions designed to a customer's specifications for converting organic material into energy products. NES also has the capabilities to destroy hazardous organic chemical waste.

NES is a private Canadian Corporation that owns a proprietary, patented technology called *GAS PHASE REDUCTION* ("**GPR**"). GPR converts organic material into hydrogen-rich methane gas. GPR is a reduction technology undertaken within a 'closed loop' hydrogen environment where there is no combustion. This process is not incineration, nor is it gasification. Organic material includes: municipal solid waste; biosolids/sewage sludge; tires; biomass; wood construction waste; hospital waste; animal waste; plastic; hazardous chemical waste; and old munitions.

Utility Patents in Canada and the United States were granted in April 2012 and January 2013 respectively, followed by Patents being granted in Australia and in New Zealand in the fall of 2015. In August 2017, the European Patent Office granted Patents to NES representing 35 countries. NES was granted its 40th Country Patent in October 2018. NES has other international patents under examination. The NES solution is expected to provide significant overall reductions in Green House Gas (**"GHG"**) emissions given that the GPR processing equipment produces next to zero emissions. GPR outperforms existing gasification, pyrolysis, incineration and similar technologies with significant savings in both capital cost and plant operating costs.

Figure 37: Generation One Thermal Reduction Processor

GPR is a proven process technology initially developed for the ***destruction*** of hazardous organic chemical waste. Three commercial plants were designed, built and operated using the First-Generation Patent technology in the 1990's being: General Motors Canada; the Government of Western Australia; and Nippon Sharyo in Japan. I addition, the US Army contracted for a demonstration scale GPR plant for the destruction of chemical and biological weapons with close to four years of successful testing. The GPR technology is known and supported by the US EPA, the US DOE, the US Military, Canadian Department of National Defense, as well as by a number of environmental groups such as The Sierra Club and Greenpeace. GPR technology received operating permits in Canada, the USA and Japan.

Water Jetting

High-pressure abrasive waterjets provide a nontraditional tool for the safe and environmentally friendly demilitarization of high-explosive munitions, whether the munition is on land or underwater. High-pressure water jets have cut and demilitarized over two million high-explosive items without incident, making it one of the safest and most environmentally friendly technologies for demilitarizing and recycling explosive munitions. Waterjets can also be deployed underwater to demilitarize high explosive munitions found on the seabed. Waterjets have been used underwater for almost four decades and have significant advantages over underwater detonation as a disposal method for munitions. Two of the major advantages in using water jets underwater are minimizing collateral damage from the detonations to infrastructure or sensitive marine environments and minimizing acoustic trauma to marine mammals that can be killed or injured using traditional detonation processes.

Figure 38: Waterjetting, 3RD International Dialogue on Underwater Munitions, Sopot, Poland

The economic advantages of using water jets with underwater ROVs are that the ROVs can operate: at depth almost indefinitely, at extreme depths well beyond where divers can safely operate, 24 h /day (if desired) with a relatively small crew, and without the health and safety restrictions and concerns (e.g.,loss of life) that accompany a dive operation.
AWJ also have the ability to cut through hardened steel and concrete structures underwater, as shown by Mammoet-Smit (2001),

by the AWJ cutting of 26 holes at 100 m (328 feet) depth in the stricken Russian submarine Kursk in 2000. The ability to cut through steel without heat or the potential of a blade jamming allows high-pressure water jets to safely access the holds of sunken ships with cargos of munitions.

An additional benefit of using water jets in the demilitarization of underwater munitions is that many of the common nitroaromatic explosives, such as TNT, are effectively rendered nonexplosive by the addition of as little as 10% water by mass according to DOT (U.S. Department of Transportation, 2010) and Munroe and Howell (1920).

Munitions containing nitroaromatics can be efficiently rendered nonexplosive by using high-pressure waterjets to dilute them prior to further handling. The hazard reduction for the recovered items from “high-explosive” to “flammable solid” is also accompanied by substantial reductions in regulations and transport costs.

Based on this new technology and the use of the water jet cutting process, conventional explosive munitions can now be quickly disposed of in an environmentally friendly manner.

Destructive and non-destructive methods to dispose of underwater munitions have greatly improved over the past decade. One aspect that has been a point of concern that is both associated with disposal of underwater munitions has been the noise levels and the environmental effects that are created when detonations occur underwater. Additionally, explosive residues from the underwater cutting process can be easily collected by localized aspiration and filtration, minimizing the release of explosive materials and limiting the potential for environmental impacts.

The harmful effect is also associated with the majority of other technologies involved in the detection and removal of underwater munitions. Offshore oil and wind power companies are studying an unusual but promising means of lessening the impact of sound on marine mammals: bubble curtains. Adapting a technique that proved successful in underwater bridge building, energy firms are testing the benefits of surrounding their operations with walls of bubbles that actually alter the shape of the noise waves. In Germany, where offshore wind farms are an important component of the nation's ambitious plans for expansion of renewable energy, the impact on the rich marine life in the North and Baltic seas has been a growing concern. Building a wind farm into the seafloor is a massive undertaking; turbines in Germany's first offshore wind project each stood about 150 meters high and weighed 1,000 tons. The German Federal Agency for Nature Conservation (BfN) listed bubble curtains as an option to meet the new standard and mask the sound of underwater wind turbine pile driving.

Wrecked Ships with CW Cargo

The danger of leakage and spreading of CW agents from the wrecked ships loaded with CW ammunition should not be underestimated. Due to corrosion of the aircraft bombs, this ammunition will collapse under their weight and that of the load of grenades. Tidal currents and turbulence caused by the passage of trawl nets and submarines may cause additional damage. In spite of the warnings on nautical charts, it was found that some of the wrecked ships in the Skagerak were covered by trawl nets.

A variety of techniques can be suggested to retrieve CW ammunition such as:

Lifting of small objects

Many ROV's (Remotely Operated Vehicles) are active in the offshore industry and those containing specialised handling tools could be employed to place dumped ammunition in a disassembly container for dismantling and (pre-)processing with electro- or thermo-chemical methods on land or on a mothership (see section 2.5)

Lifting of ships

This is difficult for several reasons: the corroded state of the vessels and their cargo, their weakened structure caused by holing the ship before sinking, their great weight and the risk of explosions which would release toxic gas when surfacing (these ammunition explosions may occur due to pressure changes between the seabed and the surface).

Sarcophaging of ammunition

The ammunition in the Baltic Sea is dispersed over a wide area, and it is impossible to cover all the dumping sites. In an emergency operation, sarcophaging should be limited to smaller sites where the CW ammunition is concentrated. For this purpose, a blanket of rock (stones and sand) 2 m high for a 250m x 250m area would require 260,000 tons and cost approximately 7.1 million EUR.

Pre-survey

A method, based on existing techniques and equipment is proposed to sarcophage sunken vessels and dumping sites with a sheet of granular material. Since the material is normally crushed rock, supplied by quarries, it is hereafter simply denominated as rock.

Prior to the installation of a rock protection, a survey has to be made to determine the seabed and sub-bottom conditions:

- soil sampling: by gravity cores, vibro-cores, cone penetration and grab samplers
- buried objects: by sub-bottom profiler and magnetometer
- seabed: by echo-sounder and side-scan sonar
- visual inspection: by eyeball ROV
- location: by global and local positioning systems.

Data have to be collected on:

- The surface to be covered, for instance in case of a ship, its length, width, height, position on, and, if partially buried, in the seabed and the condition of its structure.
- The presence of objects on or buried in the seabed..

Advantages of sarcophaging (if properly done):

- Isolate the CW agents and prohibit dispersion over a wider area;
- Protect ammunition and shipwrecks from being damaged and ruptured by foreign objects such as bottom-towed fishing gear, anchors and exploration activities;

- Reduce the speed of the ammunition's corrosion as the water is almost stagnant and the influx of oxygen thus reduced;
- Retard the release of toxic agents when the material (or combination of materials) applied has a low fluid permeability;
- Allow dissolution and disappearance by hydrolysis of the CW agents to take place in a confined site; and
- Allow chemical conversion of leaked CW agents when gels of reacting agents are added.

Methods of Sarcophaging

The method of full sarcophaging of a wrecked ship consists of building a stable mound of rock along and over the wreck. The quantity of rock needed is, for instance, 250,000 tons for a Liberty ship as used during WW-II. Example of a WWII Liberty ship wrecked with CW agents is located in the Skagerak.

The amount of rock is significantly less when a wrecked ship is already buried in the seabed or when the wrecked ship is intentionally lowered into the seabed.

- **Rock-covering**

  Whereas dumping of sand and rock was originally carried out by split-bottom and side-dumping vessels, a new generation of vessels was built in the late seventies, when offshore oil and gas installations entered deeper water and more difficult working conditions had to be overcome. These vessels are equipped with a fall-pipe system for controlled placement of the material using underwater cameras to ensure low losses during deposition.

  These vessels navigate on a Dynamic Positioning System (DPS) and time-consuming anchor handling operations are not needed. The loading capacities range from 12,000 to 18,000 tons. The fall-pipes have a diameter between 0.5 and 1.0 metres. Some have an open structure (nets with circular rings at regular distances), others have closed-wall plastic or steel pipes, stacked on top of each other. The bottom end of the fall-pipe is located within the central opening of a cylindrical Remotely Operated Vehicle (ROV). With its four thrusters, the ROV holds the fall-pipe exit with precision above the required position.

  The survey system of the ROV is linked into the vessel's DPS system, so that its position relative to the vessel and also its actual position are always known. The ROV is heave-compensated, which makes it independent of the ship's motion and it can be kept at a constant level above the seabed.

  The vessels can operate over a large depth range. Projects have been carried out in the North Sea and Mediterranean in depths up to 600 m. In the near future this range will increase considerably for deep-sea pipeline projects.

To ensure the integrity of the sand/rock-deposited structure on the seabed, at least two criteria have to be met:

- The stones in the outer layer, also called the armour layer, have to be stable under extreme weather conditions to provide the structure's permanent integrity;
- One or more intermediate layers, also called filter layers, are required when there is a big difference in particle size between the armour layer and the seabed sediments. Without such filters, there will always be a risk of seabed material being washed out through the pores of the outer layer and of the larger stones descending into the seabed.

- **Outer Armour Layer**

The material of the armour layer should be sufficiently heavy to withstand severe conditions. For this purpose, the formulated design condition must allow for extreme weather conditions in terms of a maximum sea wave (amplitude, period and direction) and a maximum storm (speed and direction), with an annual occurrence probability of 0.01 times, also referred to as a return period of 100 years. Both have to be transformed into current velocities just above the seabed with tide wave-induced velocity being a continuously varying, oscillatory vector and the wind- or tide-generated current static vector.

When stones have to be deposited at sites 100 metres deep or more, the stone size can be kept rather small (< 75 mm), as only stability variations have to be taken into account. Where fishing activities are likely, it is better to use larger material with diameters of 75 to 125 mm. Since the material is the result of rock crushing, the given size of 75-125 mm generally ranges between 25 and 200 mm.

- **Intermediate Filter Layer(s)**

It is an empirical rule for breakwaters, piers and groins that the grain-size ratio of the material in two successive layers should be less than 25. For offshore conditions, a less costly, in between solution can be applied, whereby the two layers are installed in a combined single operation. In this case the material for the filter and armour layers are mixed on land before loading. The disadvantage here is that some finer material is lost.

- **Permeability**

Pressure gradients around a sarcophaged structure are the driving force of the groundwater movements. The permeability of the used filter material can range from 1 m/sec for large stones to 0.4 mm/hour for sandy clay.40 This lower value is acceptable for halting the release of CW agents.

There are various ways of reducing the permeability of the armour and filter protection layers:

- Installation of watertight flexible mattresses filled with grout cement or asphalt bitumen. Stones placed along the edges fill the scour holes and stop erosion.
- Injection of grout cement, asphalt or polymer cement after sarcophaging. However these techniques have their technical complications: Grout requires precautions to avoid cracking and loss of pieces of concrete, and needs certain additives to prevent de-mixture during deposition. Asphalt has to be poured hot, which requires an insulated chute. This is practically impossible at depth, due to the cold sea-water environment at which the CW agents have been dumped. Polymer cement is applied as a thin liquid and requires an additive for quick hardening to avoid being flushed away. This means that there must be a well-designed application system to avoid interruption of the process. In high seas this is can be a problem!
- Application of geotextiles. These woven textiles are widely used for river banks and sea-defences. Their application offshore is only recent. Geotextiles can be spooled on large drums and spread over a wide area in one single operation. Extra weight must be added to ensure efficient lowering onto the seabed and anchoring at the site.
- Application of additives which facilitate the hydrolysis of CW agents. As mentioned in Annex I on the chemistry of CW agents, hydrolysis is accelerated under alkaline conditions. Such conditions are created with additives such as chalk. The use of ground carbonate rock, if available, for the filter layer would perhaps be a solution.

Injection of special gels. A gel called Khitozan, produced from crab shells, mixed with fly ash from coal-fired power stations was tested to isolate radionuclides in the sunken Russian nuclear submarine Komsomolets on 7 April 1989 in the Norwegian Sea, 180 miles south-east of the island Medvezhiy. Certain technical problems have to be solved before applying fluids which have to solidify beneath the armour or filter layer. If solidification is too slow, losses occur from the wreck, and if it is too rapid, the product may easily solidify in the supply hose. The gel material is also difficult to produce at a reasonable cost.

Burial of wrecked ships

Recently a new generation of trailing suction hopper dredgers (TSHD) have been built which can dredge in depths of 100 m, their use in the Baltic Sea is therefore possible. Other, slower techniques are available for greater depths, such as in the Skagerak, using water jetting, hydro-dynamic excavation and deep-water dredging. In Fig. a heavy working class ROV is given which can be equipped with various tools, such as a jet pump which produces a high pressure jet flow by which the sediment is removed. The system operates satisfactory to depths of 1700m.

Another applicable equipment (not an ROV) called Hydrodigger (Fig. 19), houses a large horizontal propeller which generates a massive downward flow of water, by which the seabed underneath is gradually eroded. An almost similar system operates under the name Jet-Prop. The operation of the Hydrodigger is limited by the length (200 m) of the flexible hose attaching it to the mother vessel. The displacement of sand is claimed to be of the order of 1500 m3/hr and somewhat less for cohesive sediments.

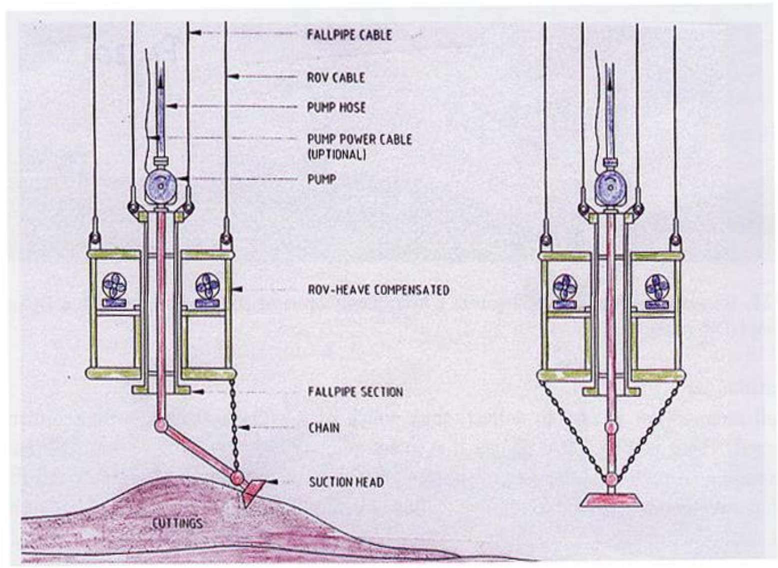


Figure 39: TIDEWAY SYSTEM

A system which TIDEWAY has proposed for the removal of drill-cuttings around offshore production platforms can also be applied. It consists of a depth independent dredging technique using an underwater pump attached to the fall-pipe ROV. Instead of bringing the dredged sludge to the surface (as in the case of polluted drill cuttings), the sludge can be thrown aside and left on the seabed. This system is designed to operate below 1000 m. (Durrsma,1999)

Perhaps an alternative would be to excavate large holes at strategic points and to bury collected ammunition in these holes under a layer of rock. The holes could be dug by the deployment of the above mentioned ROV's as dredging, jetting and hydro-dynamic excavation.

An additional method is a grab system with lateral transport, operated from a surface vessel. The large clamshell is operating hydraulically. Once the hole is ready, a working class ROV with manipulators is deployed to search the seabed and to lift and transport the ammunition underwater to the hole, where it is dumped. When the hole is full, it is covered with a sheet of rock. The ROV is powered from the support vessel, which has to follow the ROV during its movements underwater. A systematic approach is recommended, whereby the areas is subdivided in blocks, which are successively cleaned.

Disadvantages

Not all ammunition is easy to collect, since much of it will be covered with sediment and dispersed. There is also a real danger that intact ammunition may explode and that damaged ammunition, in particular the aircraft bombs, may start to leak and contaminate the ROV's, which would then be difficult to retrieve without contaminating the support vessel and its crew.

Incineration

"An open-air combustion process by which excess, unserviceable, or obsolete munitions are destroyed to eliminate their inherent explosive hazards" (DoD, 2012). OB is technically appropriate for the disposal of munitions, bulk energetics, and other waste materials that are unlikely to detonate and are more prone to burning when ignited. Examples of such munitions, bulk energetics, and waste materials include the following:

• Small arms ammunition (SAA): The only energetics in SAA are a small, smokeless powder propellant charge, a small primer, and a tracer in some SAA cartridges. These ignite or "cook off" when adequately heated, demilitarizing the SAA. OB of SAA is frequently performed in a containment cage or "popping furnace" or, in the case of CAAA, in "pipe pits." As with all OB, the resulting air emissions are released directly to the atmosphere, and residues, consisting of melted projectiles and brass cases from the burned SAA, are left in the furnace to be periodically removed.

• Bulk propellants and other non-detonating energetics: Propellants removed from SAA and larger projectiles, rockets, and missile systems, and bulk propellant from propelling charges are appropriate for OB. They are either removed from the weapons system, spread out on a "burn pan," and remotely ignited or (in the case of rocket and missile motors) can be static fired. In both cases, there is very little physical residue from the energetics remaining at the OB site, as most of the energetics is consumed by the burning process. Only small amounts of ash remain after the burn, but, as with all OB, all of the airborne emissions are released directly without treatment to the atmosphere. The ash is removed following each OB event for subsequent disposal, typically as hazardous waste.

• Bulk explosives: Some bulk explosives are suitable for disposal by OB because they tend to burn efficiently and not detonate unless they are confined and the detonation is initiated by an adequate explosive initiator, such as a blasting cap. The process for burning bulk explosives is similar to that for OB of bulk propellants. The possibility of a high-order detonation during burning exists, so adequate separation distance between the OB site and personnel and structures is required.

• Waste contaminated with propellant, energetics, and other contaminants: Some of the depot RCRA permits authorize them to dispose of flammable contaminated material by burning, usually on a bed of scrap such as contaminated wood or other flammable material. In this case the burn is often started and sustained with added fuel oil.

Open Detonation "Open Detonation" is defined in DoD Manual 6055.9-M as, "An open-air process used for the treatment of excess, unserviceable, or obsolete munitions whereby an explosive donor charge initiates the munitions being treated." Munitions and explosives that are likely to reliably detonate when initiated are technically appropriate for OD. OD is commonly performed by placing the munitions to be demilitarized into a prepared trench or pit, placing donor charges in contact with the munitions, placing prepared detonation initiators on the donor explosives, covering the prepared OD "shot" with soil removed from the trench (a process known as "tamping" designed to decrease the noise, shock, and debris ejected from the detonation), and then initiating the disposal detonation from a distant and protected location. The detonating donor explosives initiate almost immediate "sympathetic detonations" in the munitions, causing the munitions to also detonate, resulting in their demilitarization.

OD generally results in a greater amount of solid residue remaining at the site because there is usually a greater volume of inert components (such as bomb and projectile cases) input into the OD process compared to OB. Although the components and heavy steel cases of the munitions are demilitarized, they are not "consumed" by the detonation and are not actually "destroyed." The inert components are shattered into fragments of varying sizes by the detonation, and the fragmented metal components, dispersed by the detonation, remain in the disposal trench and the surrounding area as defined by the fragmentation distance of the detonation. This makes the cleanup of solid residues from OD more time-consuming and costly than cleanup of residues from OB, which are most often confined to a burn pan.

Examples of munitions that are appropriate for OD demilitarization are munitions that are filled with high explosives and are designed to detonate such as projectiles, bombs, grenades, and rocket and missile warheads. The following description of typical procedures implemented during OD operations is based on the SOPs provided by PD Demil for review. The various Army depot OD SOPs are more similar than those for OB, and the committee believes that the SOPs reviewed are representative of the procedures performed at the seven stockpile depots.

The OD SOPs are typically approximately 80 pages in length. The range maximum NEW limits are described in the SOPs, but they vary based on the size of the detonation facilities and the mission of the depot. For BGAD, OD is limited to doing disposals in 30 disposal pits with a 100 lb NEW for each pit (a maximum total of 3,000 lb per disposal detonation event). There are 6 primary demolition pits at CAAA, and the NEW limit for each pit is 500 lb, with a 70,000 lb NEW maximum allowed on the range. The CAAA range also has one pit designated for the disposal of rocket motors and a secondary range with a maximum NEW limit of 1,000 lb. TEAD has 19 detonation pits on the "TN Range" and 25 on the "TS Range," with up to 3,000 lb NEW authorized for detonation in each pit. Many of the SOPs contain prohibitions on the detonation of some types of munitions. Disposal by detonation of hexachloroethane and other riot control agents, colored smoke, white phosphorous, red phosphorus, and depleted uranium is specifically prohibited in the BGAD SOP. No prohibited munition types are specified in the CAAA SOP. The LEAD SOP prohibits detonation of "dye filled rocket warheads and Navy armor piercing rounds."

The OD SOPs contain specific weather and environmental conditions that are similar to the restrictions for OB that must exist before initiating a disposal operation. At BGAD each disposal detonation must be approved by a "planning team" that prepares a "daily authorization" for OD operations, and "surveillance personnel" must perform and document safety inspections of OD operations at least daily. The CAAA SOP has less rigid "notification requirements" to be implemented before OD is performed, and there are no specific surveillance or quality requirements, although it is possible that surveillance and quality requirements are contained in a different SOP belonging to those departments. The type of initiation (electric or non electric) varies among the Army depots with some authorized to use both.

The various depots also use different donor charges, most likely based on local availability. For example, at TEAD, TNT, Composition B, Composition C, and Bangalore Torpedoes are authorized for use as donor charges. In all cases the donor charges are initiated by detonation cord connected to initiator explosives (usually blocks of Composition 4 or TNT) that, in turn, are placed on the donor explosives. The SOPs contain the following general procedures that are performed for each detonation shot:

1. Checking continuity in the firing wire and the resistance of the blasting caps (electric initiation) or receiving the nonelectric initiation system components (for nonelectric initiation).

2. Receiving the munitions for OD and the donor charges.

3. Preparing the detonation pits by digging them at least 6 ft. deep using a bulldozer. Some of the SOPs specify different depths of excavation.

4. Placing the munitions for disposal in the prepared pits as specified in detailed SOP requirements.

5. Loading donor explosives on top of and around the disposal munitions.

6. Preparing the electric or non electric detonation system. Normally two independent systems for each detonation are used to help avoid misfires and ensure high-order detonations.

7. Placing the prepared initiation charge on the donor charge.

8. Covering the prepared detonation shot with soil using a bulldozer while ensuring that the detonation cord is undamaged and protrudes from the ground. The minimum amount of soil to tamp the shot varies in the SOPs. Above-ground shots are authorized at LEAD, but they are limited to 50 lb NEW and are performed only when the demolition supervisors have determined that above-ground OD is necessary, typically for safety reasons. BGAD specifies covering each shot with at least 6 ft. of soil. An earth cover 15 ft. deep is required at TEAD for shots larger than 50 lb.

9. Connecting the electric or non electric blasting caps to the detonating cord leading into each pit.

10. Electric initiation of the detonations from the designated safe area after ensuring that the area is clear of personnel and approval for the detonation has been received. For nonelectric initiation the time fuse igniters are actuated at the disposal pits and the technicians then depart to the safe area.

11. Procedures to be followed in the event of a misfire are included in the SOPs.

12. Upon completion of the detonations the technicians inspect the demolition area and collect large debris and kick-outs. Large debris that does not contain explosives is collected for range maintenance and recycling. That with explosives is added to the next detonation event to achieve disposal.
13. Reporting requirements vary among the SOPs with some requiring formal reports and others using log book entries.

Open-Pit burning

Since no other safe way of destruction was available,43 this method was used just after WWII and recently in Iraq to destroy 122-mm rockets, with the permission of the UNSCOM (United Nations Special Commission in Iraq). The CWC (Chemical Weapons Convention) does not however, allow open-pit burning.

Incineration plants

Most CW agents, with the exception of sarin, are inflammable and incineration is practically 100%, if properly controlled.45 In the US installation at the Johnston Atoll in the Pacific,46 the CW agents are burnt in a counter-flow rotary device for 15 minutes at 538 oC and in a subsequent after-burner for 1 second at 1200 oC. The environmentally hazardous products that are formed after incineration are: nitrogen-, arsenic- and phosphorus oxides, hydrogen-chloride and chlorine. Chlorinated toxic dioxins may be formed if the temperature is between 180 and 400 oC and when chlorine and reactive hydrocarbons are present. Therefore, during the destruction process, the period during which the incineration "off-gases" are heated should be minimised. Rapid cooling of the off-gases by water to 60 oC and removal of hydrochloric acid and chlorine with sodium-carbonate solution and the final sorption of the gases with activated charcoal will ensure that no toxins are released into the atmosphere.

Chemical methods

The techniques to destroy CW agents by chemical means are in full development. They have certain advantages over incineration since CW agents are converted into non-toxic compounds which are easier to dispose of.

Two-stage technologies are here mentioned:

- Organophosphorus CW agents

A two-stage technology has been developed by GosNIIOKhT for organophosphorus CW agents. This technique is characterised by its simplicity and meets Russian design criteria. The first stage is to react sarin for example with monoethanolamine at 100 oC, resulting in a reaction mass 20,000 times less toxic. The second stage consists of binding the reaction product (at 135 oC) with a mixture of bitumen and calcium hydroxide. This mixture is then heated to 200 oC at lowered pressure for one hour. Since sarin contains fluoride, these ions are bound during the bituminization into insoluble calcium-fluoride salts. The calcium hydroxide breaks up the phosphorus-organic binding, leading to the formation of an alcohol and a non-toxic calcium-phosphorus compound.

- Mustard agents

The most promising destruction option here seems to be a three-stage process of mustard hydrolysis, followed by a treatment with monoethanolamine and bituminization. The hydrolysis takes place with calcium hydroxide and the next two stages take place at 100-110 oC at hourly intervals. The solid bitumen blocks can be safely buried as non-toxic waste.

Plasma-chemical techniques

Research conducted by the Russian financial and industrial company "Ecotransenergomash", the designer-shipbuilders of St. Petersburg, Severodvinsk, Nizhny Novgorod and the designers of the Russian Airspace Complex has produced a promising method for transforming underwater chemical dumps by chemical, plasma-chemical and electro-discharge methods into soluble and insoluble components and for the transport of the soluble components in containers to a mother ship for treatment on-board. More information on this process can be found in the document on Dumped Chemical Weapons in the Sea - Options p 14 and 23.

Plasma-chemical techniques of incineration and decomposition by chemical reactions can, with certain advantages, also be used to destroy on sites dissolved and gaseous-phase toxic substances extracted from sea-dumped CW agents. Plasma-chemical devices are used for purification of exhaust gases, for destruction of ozone-depleting freon (CFCs), for extraction of ultra-pure silicon (silicon dioxide, silicon nitride) from gaseous-phase products, and for precipitation of diamond and diamond-like films, etching of metal and dielectric samples, etc. The thermo-non-equilibrium plasma-chemical reactor seems to present a quick, reliable and safe way to destroy CW agents and thus help to solve this pressing problem.

Five types of microwave plasma-chemical reactors can be distinguished:

1. A plasma-chemical reactor on the basis of a high-power pulse microwave generator. The advantages of the method are:

- A high efficiency (approximately ten times higher than by incineration);
- The low temperature of the reactor; and
- Possibility of installation on a mothership, in spite of its size (3x3x1m).

However, the disadvantage is the cost of a microwave generator which ranges between $30,000 and $50,000.

Obviously, this microwave reactor can only be used on mother ships. In the scheme described in the previous section, once the products of decomposition of dumped chemical weapons have been recuperated as a contaminated sea-water or lumps of CW agents and transformed into the gas phase, the pulse microwave discharge reactor can execute the final purification.

2. A plasma-chemical reactor on the basis of a consumer microwave generator

A typical 600 Magnetron of continuous action is commonly used in consumer microwave ovens. The device allows for microwave discharge at relatively high pressures in various gases and gas mixtures. When working with argon, it is possible to produce plasma at pressures reaching atmospheric value. When working with gas mixtures containing electronegative components (for example, CCl4, SiCl4, CF2Cl2, etc.), lower pressures are used. Low costs for the decomposition of chlorofluorocarbon molecules and for mixtures containing gaseous-phase toxic substances have been obtained.

The narrow interval of the working pressures is a drawback which may have an effect on the capacity of the device, but the extreme cheapness of the microwave generator and its small dimensions are the essential advantages.

3. A plasma-chemical reactor on the basis of a slipping surface discharge

This reactor differs from the former reactors in that it uses a device based on stimulating slipping surface discharges as in a plasma generator.

Its advantages are:

- simplicity and cheapness of production of discharge elements;
- possibility of producing flexible dischargers which create plasma of complex geometry (a ring, a spiral, a sphere, etc.);
- low costs of about 1-5 kW.hour/kg.

The reactor can be used on mother ships in the same way as the microwave discharge reactors and underwater vehicles, so its field of application may basically expand in comparison with microwave facilities.

4. A plasma-chemical combustion of toxic gases

The reactor based on plasma-chemical combustion of gaseous-phase toxic substances is similar to that represented in. The main difference from that described in the previous section is that the toxic product is mixed with hydrogen and oxygen in a non-detonating ratio. Simultaneous quick burning takes place in the whole volume of the chamber, the toxic products being virtually decomposed during one run (one high-voltage pulse).

Energy costs are extremely low (about 0.01-1.0 Watt.hour/kg). The method is applicable to all kind of CW agents found dumped in the Baltic Sea, and can be used on mother ships.

5. Electro-discharge purification of water from dissolved toxic substances

Plasma-chemical research is also directed towards the purification of water in Russia, the USA, South Korea and England.50 The concept of the reactor is represented in Fig. 29 A & B. A chamber (pipe), through which the processed fluid flows, contains an electro-discharge device of a special design,51 containing a system of local electrical discharges in the water medium. The plasma formation, generated on the surface of the discharge device, removes various chemical impurities from the water with a high efficiency.

The purification ability of the discharge device is dependent on the synergetic action of various factors:

- high-power ultra-violet radiation of electro-discharge plasma;
- strong sound and shock waves excited by the discharge;
- production of chemically active substances (i.e. O3) and radicals (i.e. OH);
- initiation of cavitation phenomena.

These factors add up to a low energy cost of purification of 1-10 Watt.hour/litre, or a cleaning capacity of 1 m3/hour/kWatt. The method could in principle be used on a mothership, but has not yet been tested for CW agents.

Cost Considerations

In order to set up a programme of plasma-chemical reactors of detoxification of CW agents dumped in the Baltic Sea it would be necessary to conduct:

1. Experiments on the efficiency of microwave discharges, of slipping surface discharges and of plasma-chemical combustion: execution time: 1.5 years; estimated costs: $400,000

2. Experiments on the electro-discharge utilisation of removing toxic substances dissolved in seawater. Execution time: 1 year: estimated costs: $300,000

3. Development of designs of plasma-chemical modules for surface and underwater utilisation of toxic substances: execution time: 8 months; Estimated costs: $100,000

4. Production, mounting and start-up of demonstration reactors for plasma-chemical utilisation of toxic substances: execution time: 1 year; Estimated costs: $500,000.

These systems may need to be adapted to address the specific needs relating to recovered underwater munitions, but they are accepted by regulatory agencies and are already operating at terrestrial sites in the EU, China, Japan, Germany and the United States.

Department of Defense Military Munitions Sea Disposal Site Hawaii (HI-06), referred to locally as Ordnance Reef, is off Oahu's leeward coast. Promising technologies demonstrated at Ordnance Reef (HI-06) include those for munitions recovery, at-sea demilitarization, nondestructive testing, and explosives detection. Studies on fate and transport of munitions-related compounds and corrosion are ongoing.

Remotely Operated Underwater Munitions Recovery System and Explosive Hazard Demilitarization System

Among these technologies are the Remotely Operated Underwater Munitions Recovery System (ROUMRS) and the Explosive Hazard Demilitarization System (EHDS). Both are assemblages of commercial off-the-shelf components, and each is housed in a standard 6-m International Organization for Standardization (ISO) shipping container and can be operated on a barge. ROUMRS consists of a remotely operated vehicle, manipulators, an interface between a precision GPS, and underwater navigation equipment used during recovery of UWMM. The system also transports recovered UWMM for treatment. The EHDS consists of a portable X-ray unit to allow positive identification of recovered munitions, remotely operated wet band saws to cut recovered munitions to expose their explosive fill, and low-temperature ovens to treat the exposed explosives, making the remaining material safe for recycling. Based on information compiled and analyzed during the environmental assessment, the U.S. Army determined that the demonstration and assessment of the Remotely Operated Underwater Munitions Recovery System (ROUMRS) and Explosive Hazard Demilitarization System (EHDS) would not have a significant adverse impact on either the human or natural environment (U.S. Department of the Army, 2011).The use of remotely operated recovery systems has the potential to significantly reduce personnel requirements (including a need for divers), eliminate risks and operational restrictions associated with divers, provide increased bottom time thereby increasing work efficiency, and increase worker and public safety margins.

MuniRem Chemical Disposal of Underwater Munitions

In September – November, 2015, MuniRem Environmental (MRE) was contracted through DONJON Marine Inc., to support disposal operations for munitions and explosives of concern (MEC) removed from the Confederate States Ship (CSS) Georgia in the Savannah River. MRE's scope of work was to receive, store, inert, and dispose of munitions and explosives of concern (MEC) items recovered from the CSS Georgia wreck site. These MEC items, Civil War era cannon balls, are considered to be Discarded Military Munitions (DMM). A Navy Explosives Ordinance Disposal dive team conducted an underwater UXO clearance around the sunken wreck and raised the munitions. The two primary types of munitions items recovered were 6.4 inch Brooke projectiles and 9 inch Dahlgren Mortars. Custody of 170 munitions was transferred from the US Navy to the US Marine Corps and then to the MRE team for making the constituents inert using MuniRem - a patented technology. The MRE team was composed of a Senior UXO Marine, UXO QA and Safety Navy Senior Chief, Senior Chemist and Chemical Engineer.

A MRE process was successfully applied to remove the main charge and the threat of a detonation and fragmentation of the munitions safely without disturbing the most hazardous part of the munition (the fuze). Thereafter, the amount of explosives remaining within the projectile was contained within the fuze. Subsequently, the fuze was rendered safe by unscrewing and diluting in MuniRem solution or drilling directly though the fuze body to access and neutralize the explosives again using a solution of MuniRem. All explosive material flushed from the munitions was fully neutralized with MuniRem solution for safe disposal as non-hazardous waste.

The results were automated remote disassembly line utilizing a combined chemically enhanced hydro mine process provides a unique safe and environmentally friendly non-thermal alternative solution for demilitarization. Custody was passed back to the USACE with the munitions now safe for shipment on public roads. The munitions will be conserved by the University of Texas and distributed to museums around the country.

Figure 40 : Canon ball constituents become inert

Figure 41: Projective - Cannon Ball

7. Guidelines for safety and efficient management of sea-dumped munitions

7.1. Requirement for Safety is Obvious but need Continual Improvement

For any organization, place, or function, large or small, safety is a normative concept and as a society, we expect that concepts and actions of safety are paramount. Safety can also refer to the control of recognized hazards in order to achieve an acceptable level of risk. Safety complies with situation-specific definitions of what is expected and acceptable. Hence, a child finding a dangerous munition on the beach is an extreme example of what is not acceptable in our society. However, if said beach was closed off to the public with posted warning signs, then a measure of safety has been employed to reduce the risk of danger.

Safety is generally interpreted as implying a real and significant impact on risk of death, injury or damage to property. In response to perceived risks many interventions may be proposed with engineering responses and regulation being two of the most common.

All organizations should have industry/task specific safety policies, plans and programs and have them routinely reviewed, exercised and audited. This includes the fishing vessel or a de-mining company's "normal" operations. The two have very different tasks/operations; however, they have an obligation to reduce personnel and resources exposure to loss and hazards. In the Safety world of underwater dumped munitions, a plethora of safety risks from varying tasks and strategies requiring safety programs is paramount and rather obvious.

As an aside and not the scope of this discussion; however, safety can also be associated with security. Dangerous and environmentally detrimental as the sea-dumped munitions are while in situ they may also pose security threats for possible use in hostilities or misuse by terrorists if access to the sites or munitions are available.

Safety and efficient management is required for all management strategies and includes standards and regulations for incident prevention and special operating procedures to prevent and respond to and manage incidents all under an umbrella for continuous improvement.

7.2. Safety in Management Strategies

No Action: this strategy by definition seems to have no action; hence, no requirement for safety. Despite this, it is prudent that the no action strategy to a site has been adopted because there is no safety/security threat.

Monitoring: there are many monitoring activities that require safety precautions. Firstly, adopting any site for monitoring purpose should imply that it has been proven through site sampling and monitoring that there is minimal risk in dumped munitions at the site leaking toxic substances or being raised unintentionally by fishing vessels. As for organizations hired for surveying and monitoring there industry specific safety regulations applicable to seamanship, boating operations and navigation, operating monitoring equipment and personnel diving.

Limiting Certain Actions at Sea: as above, this strategy implies minimal safety issues from the dumped munitions creating environmental and energetic occurrences. Safety guidelines from this strategy would employ uptodate and accurate positional guidance and precautions for surface and subsurface activities at that site. With this information, personnel and vessels can reduce their risks by avoiding these sites and precautions and warnings be detailed in their individual safety plans for any work/activity they may need to conduct in the site area. Given blast radii of various munitions, such limiting actions need be respected outside the safety radius of the "limiting certain actions at sea" site.

Neutralization at Sea, Detonation in Situ and Recovery and Destruction strategies are similar in safety guidelines in that the strategies imply that there are documented and obvious threats of environmental and safety hazards. Toxic and energetic hazards have been identified and may be eminent. For this reason, plans are in place to remove the these environmental and safety threats. Safety guidelines in this strategy would include those for monitoring such as there industry specific safety regulations applicable to seamanship, boating operations and navigation, operating monitoring equipment and personnel diving. This strategy goes much further due to the dangers of neutralizing, recovering or detonating munitions for obvious reasons. The strategy could be similar to underwater construction related safety already employed. Under water the laws of physics and chemistry function differently. This needs to be part of the training of anyone that will work underwater. Welding, for example, functions differently underwater. Chemicals react differently. The weight of objects is less and things move slower underwater.

No one should be attempting any underwater work unless they have been properly trained and proper training should be from a reputable certified school.

It must be noted that any organization performing any work (land, sea (surface or subsurface) must have a detailed safety plan visible to all workers and inspectors available at the work site. This is a requirement for most jurisdictions and for insurance purposes. Construction or high risk safety plans should include:

- Roles and responsibilities for all team members
- Safety preparedness guidelines before construction begins
- Contracted document with details of all safety requirements
- Frequent construction site inspections
- High-risk activities during construction
- Potential hazards on the construction site
- Emergency recovery and evacuation procedure
- Policy on substance use/abuse

Furthermore, Safety construction plans are not only valuable to worker's safety, but they ensure the health and safety of the environment of the construction site and the surrounding public. It is important to be cautious of hazardous pollutants, spills, or any environmental damage, and create a plan to respond to environmental harm if it occurs.

7.3. Safety Precautions:

The Helsinki Commission, through its ad hoc Working Group HELCOM CHEMU, has evaluated the present risks of the dumped CW ammunition. They have recommended that the Baltic States and Norway should jointly act in emergency situations. They are bound, both by the Helsinki Convention and UNCLOS-III (Third United Nations Convention on the Law of the Sea) to take "appropriate measures":

- anticipate and plan for emergency situations to occur through safety management plans.
- Supply safety guidelines to authorities in dealing with chemical munitions caught by fishermen, as prepared by HELCOM CHEMU and accepted by the Helsinki Commission, is an essential step towards taking "appropriate measures", however, these measures are insufficient to deal with large or small catastrophes caused by chemical munitions.
- The risk areas where it is recommended not to anchor or to fish as defined by HELCOM CHEMU (1995) need to be clearly marked on nautical charts to make it clear to the sailors and fishermen, carrying out their work in the Baltic Sea and Skagerrak, to minimize risk.
- In a number of cases, confinement and destruction measures can be taken to prevent emergency situations. They are:
  - Sarcophaging of the wrecked ships, located in the Baltic Sea and Skagerrak; and
  - Seabed burial or/and destruction of scattered CW ammunition which are not within the Allied Forces dump sites east of Bornholm and south of Gotland.

7.4. Steps for Safety to be Taken in Baltic Sea States

- Update the official nautical charts provided by the hydrographical authorities of States to indicate the locations of all CW ammunition and wrecked ships with CW cargoes on (or in) the seabed.
- The States parties of the Helsinki Convention should jointly prepare and develop contingency plans for use in case of imminent danger to the human and marine environment.
- Joint Baltic emergency teams composed of defence and coastal rescue authorities should be created in order to provide immediately help to victims of CW contamination.
- Rules and disaster information and financial compensation for victims, including treatment and insurance should be harmonised by the Baltic States and Norway.
- In order to protect and preserve the marine environment, States should always take the most far reaching measures to monitor, prevent, reduce and control pollution caused by sea-dumped chemical weapons. This includes support for the development of technical means to prevent such pollution and support for the further development of international rules and procedures for the protection of the marine environment against sea-dumped WWII chemical weapons.
- It is recommended to add a protocol to the Helsinki Convention entitled "Protocol on Marine Environment Protection against CW agents dumped after the Second World War in the Baltic Sea and in the Skagerrak and Kattegat straits", in order to establish the legal principles upon which the coordination and financing of the emergency technical operations can be based. In the drafting of this protocol the responsible authorities for marine and coastal affairs (i.e. Navy, Fishery and Coastguard of the Baltic States) should be involved from the start, as well as the experts available within the OPCW.

7.5. Human encounters with dumped chemical weapons

The Helsinki Commission have not yet (1999) published ant clear figures, mainly because several Baltic States, such as Germany have no legislation on the obligation to report findings of CW material. This is not the case for Denmark, where fishermen are compensated for retrieval of captured CW material. 439 were recorded between 1976 and 1992 (101 of these in 1990). However, since 1946, human contact with dumped chemical weapons has certainly occurred, mainly by fishermen bottom-trawling in risk areas of the Baltic Sea and ignoring warnings to avoid dumping sites.

Between 1946 and 1984, 197 cases of people suffering from mustard gas exposure were reported and a total of 171 patients were treated; 26 of these were actually admitted to hospital.

Additionally, some munition findings in the Baltic Sea often occur outside the official dumping sites and 123 people were burnt between 1955 and 1970 by CW agents on Polish beaches, where high seas had carried barrels of mustard gas. The most serious incident was in 1995 when 120 children were playing near an eroded barrel. The first symptoms of skin burning and severe eye injuries appeared after only 30 minutes. Another accident occurred on 28 January 1997 when the fishing vessel KOL-158 caught 20 kg of a strange clay-like material in the central part of the Baltic Sea. The material was immediately thrown overboard, and the vessel returned to its home port, but the crew suffered the next morning from the first symptoms of burning.

7.5.1. Lethal concentrations, symptoms and first-aid treatments

These concentrations and first-aid treatment have been prepared for the five classes of CW agents dumped in the Baltic sea and Skagerrak (Dumped Chemical Weapons in the Sea - Options- (Tables 2 and 3). (Durrsma,1999)

Table 2 : Type of warfare gases, their mechanisms of action and lethal concentrations Cl-acetophenone as tear gas is not included in this table.

Type of CW agents Mechanism of action Lethal concentration	Type of CW agents Mechanism of action Lethal concentration
Nerve agents (Organo-phosphorus compounds) Tabun, GA Sarin, GB Soman, GD	Inhibition of the enzyme acetylcholinesterase causing poisoning by excessive accumulation of acetylcholine. 400 mg-min/m3 100 mg-min/m3 50 mg-min/m3
Blood agents	Cyanide forms reversible complex with respiratory cytochrome oxidase enzyme system. In particular is the central nervous system of the respiratory

Type of CW agents Mechanism of action Lethal concentration	Type of CW agents Mechanism of action Lethal concentration
Hydrocyanic acid Cyanogen-chloride	centre susceptible and failure causes death 5000 mg.min/m3 11000 mg.min/m3
Lung-damaging (choking) agents Phosgene, CG & Diphosgene, DP Chlorine	Cyanide forms reversible complex with respiratory cytochrome oxidase enzyme system. In particular is the central nervous system of the respiratory centre susceptible and failure causes death 3200 mg-min/m3 20000 mg-min/m3
Vesicant (blister) agents N-Mustard (HN, N-Lost) S-Mustard (Yperite, H, S-Lost) Lewisite, L (arsenical vesicant)	Powerful alkylating action on DNA, and amino, thiol, carboxyl, hydroxyl and phosphate groups in cells. 4500 mg-min/m3 1500 mg-min/m3 (carcinogenic) 1300 mg-min/m
Nose and throat irritant agents Adamsite, DM (vomiting agent) Clark I,DA Clark II, DC	Blocking of enzyme action in cells through binding of arsenic by -SH-groups of these enzymes 15000 mg-min/m3 15000 mg-min/m3 10000 mg-min/m3 (all: 0.0037 mg As/l drinking water criteria LC50 Fish As: 0.9-2 mg/l)

Table 3 : Human Symptoms and First Aid Treatments

Symptoms	First aid treatments
By inhalation symptoms appear rapidly: Tightness of chest, rhinorrhoea, salivation, miosis with dimming of vision, difficulty in accommodation, frontal headache, transpiration and convulsions, cardiac arrest.	Use decontamination kit. Cleaning of eyes , skin, and clothes; slow intraveinal injection of atropine sulphate (2 mg AS) and pralidoxime (500 mg); swallowing a 5 mg tablet of diazepam; artificial respiration. Each half hour injection of 1 mg AS until slowing down of bronchial secretion.
Symptoms appear very rapidly on central nervous system. Powerful respiration and violent convulsions occur within 30 seconds and cessation of respiration within 1 minute. At lower concentrations vertigo, nausea and	Immobilising, keeping warm, artificial respiration. Treatment: with dicobalt edetate (300 mg/20 ml) called Kelocyanor, but only in severe cases (is toxic to the liver and kidneys), to be slowly followed with

Symptoms	First aid treatments
headache, convulsions and coma.	intravenous dose Sodium thiosulphate (25 g in a 50% solution).
Latent period may last 30 minutes or more. Respiratory problems pulmonary oedema, dyspnoea, cyanosis, vomiting, convulsions.	Keeping warm and at rest, rinsing of eyes, treatment as for shock and bronchial-pneumonia with codeine phosphate (30-60 mg). Steroid inhaler can be life-saving, with an initial dose five times higher than for asthma. Also oxygen therapy.
Possible latent period, redness of skin, eye troubles, diarrhoea, convulsions, fever, headache. Skin: blistering, necrosis extends into dermis. Respiratory system: inflammation followed by necrosis and pulmonary oedema. By swallowing: along the alimentary tract oesophageal and gastric mucosa, causing necrosis and perforation. Immediate pain in eyes, skin and respiratory system. Erythema, vesication and eye injury develops faster than with S-mustard. Effects being severe within 4-8 hours. Coloured urine, blue lips, haemorrhage, tiredness, followed by systematic arsenic poisoning.	Keeping warm, rapidly rinsing eyes with plenty of water or 2% sodium bicarbonate. Treatment as for heavy-degree burns. Decontaminating skin and clothes by cleaning with petrol or oil, later with warm soap water. (Due to low solubility in water and higher solubility in nonpolar liquids such as petrol and oil - see Annex I -; also oxidisable with hypochlorite). As for S-mustard casualties. In addition local treatment for eyes and skin with dimercaprol (BAL) 5% solution in arachis oil with benzyl benzoate. Can be used for intramuscular injection of 2.5 mg/kg body weight deep into the buttocks every 4 hours followed by 4x/day for 2 days, than 2x/day for 10 days.
Intense sneezing and coughing, respiratory problems, headache, dizziness. Later poisoning by arsenic compounds of liver, kidneys and red blood cells.	Inhalation of chlorine in weak concentration. Decontamination with hypochlorite, chloramine or permanganate solution.

7.5.2. Long-term effects

Few accessible documents exist on the long-term somatic and genetic effects of any kind of poison, but it is well-known that, once intoxicated, people may suffer for very long periods from vague to serious complaints, often difficult to diagnose. Gulf-war syndrome is an example and also the intoxication following the EL-AL 747 accident in Amsterdam. Similar cases may also occur after bacterial food intoxication, causing persistent allergy or sensitivity toward additives in frozen and canned food. Survivors from gas attacks during WW-I tell how they have suffered from "weak lungs" most or all of their lives. Charlotte

Auerbach (1899-1994) was a world authority on mustard gas effects. In 1940, Professor A.J.Clark of the University of Edinburgh, asked her to discuss possible effects of mustard gas on gene mutation. Prof. Clark was impressed by the long-lasting effects of mustard gas on human cells: wounds were slow to heal and liable to open up again later; ophthalmologists in 1939 were still treating ulcers of the cornea produced by exposure to mustard gas in WWI. These long-lasting effects seemed similar to X-rays effects. Thus it occurred to him that mustard gas, like X-rays, whose mutant effects were known, might also alter genetic material in the cell nuclei. Charlotte Auerbach made most of her genetic studies with Drosophila flies and found evidence not only for delayed mutations but also for the reproduction of these mutations. This latter phenomenon has remained controversial and was "very much a puzzle" for her. The greatest danger from sub-lethal intoxication by mustard gas may well be from genetic damage inherited by descendants. Although proved for Drosophila flies, the genetic damage depends on dose-response relationships and the effective filter in the embryogenesis. No documents have been found describing malformations of children whose parents survived the gas attacks of WW-I, or for A-bomb survivors in Japan who received high levels of radiation. Adequate information on CW intoxication is difficult to obtain from modern geneticists who work mainly on other topics. However the threat is there.

7.5.3. Ecological effects

The threat of dissolved CW agents to the Baltic marine environment itself can be eliminated according to information available to the Helsinki Commission. However, 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.

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 navaga 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 a 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. As far as mustard gas is concerned, and due its instability in a dissolved form, the most serious contamination is through contact with the lumps on the sea bottom, which is why so many starfish were killed in the Dvina Gulf.

7.5.4. Guidelines for Fishermen or Vessel Operators

In the final report of ad hoc Working Group on Dumped Chemical Munitions (HELCOM CHEMU) to the 16th Meeting of the Helsinki Commission, preventive measures and first-aid guidelines are given to the contracting parties in order to elaborate National Guidelines for fishermen on how to deal with caught chemical munitions. These guidelines can be summarised as follows:

First Actions:

- Turn the vessel immediately to keep the crew up-wind. Close doors and stop the ventilation system.
- When on a beach, stay up-wind of the suspected item.
- Start immediate decontamination of people, even if no adverse effects are felt at first.
- Contact port authorities for instructions.

First-aid equipment

One "gas box" for each three crew members should be available on board, containing: 5 tongue spatulas; 4 packets of absorbent cotton; 3 bottles "Gas-decontamination liquid"; 3 powder sprays, "Anti-gas powder"; 1 bottle "Anti-phosphorus liquid"; 10 atropine/oxime automatic injectors for every three crew members; 1 instruction leaflet. Protection clothing, such as presented in the Figure 42 below:

Figure 42: Protective clothing as recommended for decontamination of a contaminated fishing vessel. Illustration reproduced by courtesy of MATISEC, P.O.Box 26, 38080 St. Alban de Roche, France.

Some propose that appropriate Site Selection for destruction facilities is critical with proper seismic design and minimize potential impacts from a tsunami. Socially planning (not in my backyard) also needs to be considered. Any destruction facility siting is inevitably near the sea. “How Safe is Safe Enough” should be the eternal theme of any designer with balance between acceptable risks and costs.

Guidelines for safety are a common threat throughout each management strategy. Safety Standing operating procedures are similar but also industry specific to the task at hand. Organizational and personal safety issues are paramount for the implementation of the management strategies and eventual work implemented. Policies and standing operating procedures must be known by all personnel to prevent and if necessary proactively react to risk occurrences. The contracting organization must also ensure that the contracting party performing work demonstrates and makes available to all workers and inspectors, the worksite safety plan to best protect life and assets.

8. Cost considerations

The true cost of a project for monitoring, recovery and/or destruction operation/project is always in the final contractual bid. Even with using expert cost estimators, such prices can vary within 25% given the many complexities and value to the industry construction market.

The best price will be through a competitive bidding process but detailed construction specifications need be developed.

Cost are very important but should not be a factor in choosing a strategy. For example, monitoring costs for one site may exceed that for a response action strategy. The most important factors on costs (value for money) is fiscal management in the planning and project/program management phases.

The entire cost of a chosen strategy/option needs consideration:

•Cost of doing nothing and the ensuing existing and potential economic losses;
•Social and political trust and reputation; and
•Cost of the project (planning, implementation, continuous monitoring (if needed) and considering various funding streams through various national or international programs.

Generally speaking Management Strategies are more costly in implementation from strategies 0-5 but as mentioned earlier should not be the only factor because some monitoring sites may be more expensive that some recovery and destruction ones.

Factors Affecting Cost – **Site Conditions** (no two **areas** are the same)

- •Munition type (chemical, conventional)
- •Munition integrity – structural casings subject to corrosive effects of seawater and water pressure changes exacerbating existing leaks
- •Dispersed vs concentrated deposits (i.e. within a wreck)
- •Buried in sediment or biological growth
- •Topographical irregularities on the seafloor (sonar false hits)
- •Depths, currents, winds

Factors Affecting Cost – **Construction**(no two **projects** are the same)

- •Design – Bid – Build **vs** Design Build
- •Type of Contract – lump sum or fixed price, cost plus, time and material (when the scope is not clear), Unit Pricing
- •Contractor (incl consultant) availability and capability
- •Qualifications, standards, equipment chosen to use
- •Current market conditions, **who is contracting**, contract location
- •Bureaucratic nature of Contract Implementation
- •Funding approval process
- •Design and specification (planning) development
- •Tendering and evaluation processes
- •Contract implementation, supervision and evaluation

Even though it is complicated to give an exact calculation on the costs of the different management options, a general evaluation can be made to illustrate what aspects are of specific operations need to be taken into account and what the annual costs are of these individual aspects. Essentially, there are six factors that must be taken into account when considering costs for each managment strategy: the size of the site, the duration of the visits, the specific activity that needs to be carried out, the equipment needed, the personnel involved, and the consumables needed. However, the evaluations of the cost of certain operations mostly depend on the type of equipment used. Based on case studies from the past, assumptions can be made.

The same is for navigation where one could employ magnetic compass for navigational direction and mapping with no restrictions or employ an internal navigational system (INS), for better mapping accuracy, that is subject to International Traffic in Arms Regulations (ITAR). ITAR is a United States regulatory regime to restrict and control the export of defense and military related technologies to safeguard U.S. national security and further U.S. foreign policy objectives. Some countries are prohibited the use of ITAR technologies for use in AUV's and ROV's. A country's cam applies additional duties, tariff and taxes that can further increase costs for importing sensors.

A remotely operated vehicle (ROV) is an unoccupied underwater robot that is connected to a ship, wharf or plat-forum by a series of cables. These cables transmit command and control signals between the operator and the ROV, allowing remote navigation of the vehicle. An ROV may include a video camera, lights, compass, INS, samplers, sonar systems, and articulating arm/s. The articulating arm is used for retrieving small objects, cutting lines, or attaching lifting hooks to larger objects, relocating or recovering munitions or setting charges to blow-in-place. Cost will change similar to AUV's, as technology, manufactures, countries, legal requirements, depth, taxes and end use requirements change.

While there are many uses for ROVs, some of the most common hydrographic applications include object identification (for submerged navigation hazards) such as the recovery, relocate and disposal of underwater munitions. An ROV is not intended to be a replacement for a diver investigations, but serves as a substitute if divers are not available or diver safety is in question. ROV are use today to inspect, sample, relocate or recover chemical and conventional munitions. Costs are a consideration when determining what approach to employ.

Both the costs of divers and ROV's can increase with depth, but the risk to a diver can determine the final approach, which is not a way the most economical approach. Other considerations for costs, include training and qualifications, mobilization and demob, local considerations, regulations, client's requirement or end use and the duration of the survey or monitoring.

Table 4 illustrates the cost in Euros € of using various technologies in various scenarios of conventional and chemical munitions (dispersed, clustered, buried) within shallow, medium and deep waters and describes the approaches recommended with estimated costs.

Table 4: Cost Technical Table for Various Scenarios € Euros

	Shallow Depth 0-9 m (based on *hard sea bottom*)			Management Strategy 1,3,4,5	Approach	Estimated Cost of Scenario (€)
Conventional	Dispersed	Clustered	Buried		Typical Cruise per day via 10 person RIB includes mobilization and demobilization costs	$4,500 per day X 2 day clustered X4 day dispersed Add 25% for buried
	x	x	x	1	• Sampling approaches using divers and analytical costs ○ Passive samplers ○ Grab samplers	• $15,000 per sq km (clustered) and add 25% for Dispersed or Buried munitions. • Costs reduced by 25% for passive and grab due to reduced cost of divers required and are $500 per sample
	x			1	Monitoring approaches for conventional and **dispersed or clustered** munitions at shallow depth • Area Wide Survey using AUV (IVER, HUGIN)	• $25,000 per sq km[1]
	x	x			• Towed Array Sonar	• $35,000 per sq km
	x	x			• Towed Array Synthetic Aperture Sonar	• $45,000 per sq km
	x	x	x		• ROV	• $3,000 per 10 munitions[2]

[1] Economies of scale for greater amount of sq kms. i.e. 10% less for the second sq km, 15% less for the third -fifth sq km.

	x	x	x		• Sub-bottom imaging detection	• $4,500 per 10 munitions
	x		x	1	Monitoring approaches for conventional and **clustered or buried** munitions at shallow depth • Buried munitions using Towed Array Magnetometers	Reduce by cost by 10% for clustered and add 25% for Buried munitions from the $45K baseline cost. • $45,000 per sq km based on 3 x magnetometers. Cost increase for each mag.
		x		1	• Divers	• $5,000 per 10 munitions, add 25% for dispersed, buried.
	x		x	1	• Data Fuzing: Magnetometer and side scan technologies	• Same cost as sonar technology but add 25% for data processing of both data layers.
	x	x	x	3	Neutralization at Sea approaches Not applicable for shallow depths.	N/A
		x		4	Detonation inSitu approaches • Blow in Place Detonation via divers • ROV and manipulators (from ship)	• $5,000 per 10 munitions add 25% for dispersed. Buried N/A • $3,000 per 10 munitions add 25% for dispersed. Buried N/A
	x		x	4	See above Detonation inSitu	Same approach and technology; however, the cost increases by 20% for dispersed and 30% for buried.

[2] Cost is in per 10 munitions because it would be the same for 1-10 munitions.

		x		5	Recover and Detonation approaches[3]
					• Detonation Chamber
					    ○ Includes recovery by diver, floatation bags or ROV or UOR.
					• Water Jetting
					    ○ Includes recovery by diver, floatation bags or ROV or UOR (Underwater Ordinance Recovery).
					• Incineration or open pit burning
					• Dredging
						• $25,000 per 10 munitions (not including large original capital costs of plant valued in the millions of Euros)
						• $8,000 per 10 munitions (not including large original capital costs of plant valued in the millions of Euros)
						• $10,000 per 10 munitions (includes recovering munitions from bottom, but not the overland transportation costs to incineration site)
						$ 5,000 per 10 munitions (add 25% for buried or dispersed)

	x		x		As Above	Same approach and technology; however the cost increases by 25% for dispersed and for buried

[3] For dispersed or buried add 25% for surface recovery operations

In general, the costs increase the deeper the level. For example, in monitoring and sampling activities, greater depths require longer cable and larger ships to accommodate. Add 25% to the conventional shallow scenario costs. Therefore, the only additions to this scenario table will be in those technologies applicable to medium depth, conventional munition scenarios.

	Medium Depth 9-152 m ***(based on hard sea bottom)***			**Management Strategy 1,3,4,5**	**Approach** *As above with conventional shallow scenarios but with the following differences*	**Estimated Cost of Scenario (€)**
	Dispersed	Clustered	Buried			

Conventional	x	x	x	1	• Divers requiring deeper depth equipment
					  ○ Passive samplers
					  ○ Grab samplers
						• $20,000 per sq km (clustered) and add 25% for Dispersed or Buried munitions.
						• Costs reduced by 25% for passive and grab due to reduced cost of divers required and are $600 per sample

		x	x	3	• Neutralization at Sea approaches burial, rock covering, sarcophaging etc..	• $35,000 per 10 munitions for clustered and this method would not be viable for dispersed munitions and only for buried munitions that are also clustered and not dispersed. • Consideration for continued costs in monitoring for burial constructions will be required.
	x	x	x	**5**	• Romotely Operated Underwater Munitions Recovery System	• $10,000 per 10 munitions and (not including large

					(ROUMRS) and Explosive Hazard Demilitarization System (EHDS)	original capital costs of plant valued in the millions of Euros). • Add 25% for dispersed or buried munitions.

In general, activities relating to chemical munitions are similar to conventional munitions. Some differences are that divers may wear chemical suits and the surface vessel will have additional chemical safety precautions and equipment. The additional costs accrued due to dispersed or buried munitions is as per the convention munition scenario. Therefore, the only additions to this scenario table will be in those technologies applicable to shallow depth, chemical munition scenarios.

	Shallow Depth 0-9 m ***(based on hard sea bottom)***			**Management Strategy 1,3,4,5**	**Approach**	**Estimated Cost of Scenario (€)**
	Dispersed	Clustered	Buried			
Chemical	x	x	x	1	Sampling and monitoring approaches	Add 10% to costs of conventional shallow scenarios due to added risk and precautions taken for chemical munitions and add the required 25% for dispersed and buried munitions.
				5	Open Pit Burning is not applicable to Chemical munitions	N/A
	x	x	x	5	Plasma Chemical Techniques	Similar costs to detonation chamber as per conventional shallow scenario
	x	x	x	5	MuniRem Chemical Disposal	$500 per one munition (not including large original capital costs of plant valued in the millions of Euros). Add 25% for the additional costs of dispersed or buried munitions.

As stated in previous Conventional, Medium depths scenario, the costs increase the deeper the level. Add 25% to the chemical shallow scenario costs. Therefore, the only additions to this scenario table will be in those technologies applicable to medium depth, chemical munition scenarios.

	Medium Depth 9-152 m (*based on hard sea bottom*)			**Management Strategy 1,3,4,5**	**Approach** ***As above with chemical shallow scenarios but with the following differences***	**Estimated Cost of Scenario (€)**
Chemical	Dispersed	Clustered	Buried			
		x	x	3	Dome Encased Chemical Munition Recovery and Destruction	A large operation with huge set up costs. Costs would decrease due to economies of scale and not applicable for dispersed munitions. Based on 100 munitions the construction is likely in the $2-3 M range.
	x	x	x	1	• Utilizing submersible vehicles • Using AUV • divers	• $5,000 per day • $7,000 per day • $5,000 per day per diver

In general, there are wrecks at all levels; however, for the Baltic Sea known wrecks are in the Deep Level. As stated in previous Chemical and Conventional, Medium depths scenarios, the costs increase the deeper the level. Add 25% to the Conventional medium scenario costs. Therefore, the only additions to this scenario table will be in those technologies applicable to deep depth, chemical and/or conventional munition scenarios.

	Deep Depth 9-152 m *(based on hard sea bottom)* IN A WRECK	**Management Strategy 1,3,4,5**	**Approach**	**Estimated Cost of Scenario (€)**
Conventional or Chemical	Dispersed, clustered or buried N/A	1	Monitoring as per medium depths except the use of divers requiring mix gas, saturation, diving bell or atmospheric suit.	Add 25% to diver's costs at the medium depths level
		1	• Submersible Vehicles • Autonomous Underwater Vehicles (AUV)	Add 25% to vehicle's costs at the medium depths level
		3	Neutralization at Sea approaches, burial, rock covering, sarcophaging etc..	• Add 25% from Medium depths
		4	As per medium depths	• Add 25% from Medium depths
		5	As per medium depths; Remove individual munitions or raise the ship then remove munitions	• Add 25% from Medium depths • $1M per 10ft of ship to raise to surface (does not include overland transport costs)

Table 5 is a table summarizing the availability of different technologies with advantages and disadvantages used at Shallow to Medium water depths. It also depicts what technology is used for different Management Strategies. The table 5 does depict some costs in Euros; however, these costs unlike the one in Table 4 is not on a per unit scale (i.e. cost per x# of munitions or cost per x# sq kms). This table is informative as per the technologies available and the daily costs associated with those technologies.

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
Wide Area Detection Technologies	Towed Array – Sonar	S,M	-Minimal cost “Unlimited” power (function of towing platform) -Real-time data acquisition/man in the loop	-30-year-old technology · Requires a large support effort · Cannot detect ferrous materials · Position accuracy problems · Depth limited to tow-cable capacity · Slower, large turns at end of survey runs, limited maneuverability ·Positioning difficult at deeper depths	1	3000 – 10,000 Daily With Operators	-Can determine boundaries of a UWM Site -Determine is UWM Sites boundaries spreading -Can determine surface anomalies -Size of vessel can determine major portion of cost
	Towed Array Magnetometers	S,M	-Minimal cost “Unlimited” power (function of towing platform) - Real-time data acquisition/ma n in the loop · Rapid coverage · Can detect ferrous material	-30-year-old technology · Requires a large support effort · Position accuracy problems · Depth limited to tow-cable capacity · Slower, large turns at end of survey runs, limited	1	3000 – 10,000 Daily With Operators	-Can determine boundaries of a UWM Site -Determine is UWM Sites boundaries are spreading -Can detect subsurface anomalies -Size of vessel can determine major portion of cost

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
				maneuverability ·Positioning difficult at deeper depths			
	Towed Array Dual System Sonar/Magnetometer	S,M	Minimal cost "Unlimited" power (function of towing platform) · Real-time data acquisition/ma n in the loop · Combines the detection signatures of both sonar and magnetometer	30-year-old technology · Requires a large support effort · Position accuracy problems ·Depth limited to tow-cable capacity Slower, large turns at end of survey runs, limited maneuverability ·Positioning difficult at deeper depths	1	4000 – 12,000 Daily With Operators	Can determine boundaries of a UWM Site -Determine is UWM Sites boundaries are spreading -Can detect subsurface and surface anomalies -Creating Multiple Data Layers
	Towed Array Synthetic Aperture Sonar	S,M	Enhance resolution ·Increased target identification capability ·Low power consumption ·25% greater resolution ·3,000%	-High cost to purchase -Multiple Survey passes required to collect data	1	4000– 12,000 Daily With Operator	-Synthetic Aperture Sonar application better served on AUV and ROV's for data collection quality - Can detect subsurface anomalies in high quality resolution

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
			increase of area coverage ·Suited for use in AUV's				
	Autonomous Underwater Vehicle (AUV)	M	-Speed independent of depth ·Depth limited only by vehicle design (deep depths capable) ·Better line tracking during surveys ·Significant maneuverability-low turning radius	-Limited hovering capability ·Power limited by battery life -Vehicle can be "Lost at Sea" due to inexperienced operator, technical or exceeding the capabilities of the AUV	1,3,4,5	1000 – 15,00 Daily With Operator	-Batteries Packs can be changed-out during AUV Operation - Can be fitted to detect subsurface and surface anomalies -Chemical Sensors -Costs depended on depth rating of AUV and Instrumentations
Localized Detection Technologies Environmental Sampling/Characterization Technologies	SCUBA Divers	S, M	-Human evaluation -Accurate samplings	-Depth restriction (30.48 meters) ·Limited search time · Diver Safety issues ·Divers Restriction · Increased exposures to human risks	1,3,4,5	500 – 5000 (500 + per Diver Daily)	-Low cost in sheltered waters -Low coverage area for sampling -can require back-up divers and vessels -vessel costs can have a major impact on costs

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel)	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
	Surface Supplied Divers	S, M	-Human evaluation ·Second person verification via camera ·Immediate excavation of contacts	Depth restriction 57.9 meters	1,3,4,5	1500 – 10,000 Daily	-Vessel costs and the number of divers required can have a major impact on costs
	Surface/Subsurface Collection from Boats	M	-Easy to obtain ·Minimal cost ·Enhances human evaluation · Minimizes human exposure	Less accurate sampling		500 -2000 Daily	-Good approach for in-land or protected waters
Environmental Sampling/Characterization Technologies Localized Detection Technologies	Mixed Gas Divers	M	-Divers work independent of support vessel ·Human evaluation	-Personnel requires specialized training ·Requires specialized support equipment ·Maximum working depth (Nitrogen 190 ft.) (Helium 300 ft.)	1,3,4,5	1500 – 5000 Daily	-ROV's can remove human risk -can increase costs and risk
	Atmospheric Divers	M	-Human evaluation ·No decompression	Personnel requires specialized training	1,3,4,5	2000 – 15,000	-High-Risk -Deepest Dive by

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel)	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
Environmental Sampling/Characterization Technologies			requirements for divers -Accurate sampling	·Requires specialized support equipment ·Maximum working depth 610 meters		Daily	Human for UXO 410 metres -Hypobaric Chamber and Vessels costs to consider
	ROV	M	-Depth limited only by vehicle design (deep depths capable) ·Exceptional maneuverability and hovering ·“Unlimited” power (function of host platform) ·Able to manipulate items -Removes Human Risk	-Very limited horizontal movement -Sometime requires DP Vessel for positioning -Requires UBSL	1,3,4,5	500 – 10,000 Daily	-Can employ multiple detection and -sampling technologies -Cost dependent on rating depths and sampling tools
	Autonomous Underwater Vehicle (AUV)	M	-Speed independent of depth ·Depth limited only by vehicle design (deep depths capable) ·Better line tracking	-Limited hovering capability ·Power limited by battery life -Limited sampling capability	1,3,4,5	1000 – 10,00 Daily	-Batteries packs can be replaced between operation --Cost dependent on rating depths and sensors

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel)	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
Environmental Sampling/Characterization Technologies			during surveys ·Significant maneuverability				
	Saturation Divers	M	-Human evaluation -Accurate Sampling	-Personnel requires specialized training ·Requires specialized support equipment ·Maximum working depth 290 meters	1,3,4,5	1500 – 15-000 Daily 1 Diver 1000 – 1500 Daily	-Increased human risk -Hypobaric Chamber and Vessels costs to consider
Localized Detection Technologies	Hand Held SONAR	S,M	-Easy to obtain ·Easy to employ ·Minimal cost ·Enhances diver search capabilities	Cannot detect ferrous materials	1,3,4,5	100 - 1000 Daily	-Real-time reading and results -Human error or value added
	Hand Held Magnetometer	S,M	-Easy to obtain ·Easy to employ ·Minimal cost ·Enhances diver search capabilities		1,3,4,5	100 1000 Daily	-Real-time reading and results -Human error or value added
	Remote Cameras	S,M	-Enhances human evaluation ·Minimizes human exposure	Hard to focus and view underwater anomalies	1,3,4,5	10 to 100 Daily Depended on the	-Real-time monitorin-24/7 Monitoring

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
			·Highest resolution Best method for identification of exposed items			numbers of cameras and depths	
Environmental Sampling/ Characterization Technologies	Surface/Subsurface Collection from Boats	S,M	-Easy to obtain · Minimal cost ·Enhances human evaluation ·Minimizes human exposure	Less accurate sampling	1,3,4,5	500 – 1000 DAILY	-Low costs approached
Response Action Technologies	Floatation Bags	S,M	Accurate retrieval	Increased risk to divers	4,5	100 - 1000PER BAG	-Bag and Cadge
	Dredging	S,M	Large volume removal	-Increased risk of detonation ·Destruction of coral or endangered species ·Inability to recover individual items of ordnance	4,5	20,000 – 100,000 Daily	-Cost dependent on vessel and depth of dredging
	Mechanical Manipulator	S,M	Accurate retrieval ·Remote operation	-Requires frequent repositioning	4,5	Daily low cost from	-can be developed job perceptive

Table 5 : Table Summarizing the Availability of Different Technologies

Type of Technologies	Resource (Equipment/Personnel	Depths	Advantages	Disadvantages	Strategies can be used 0-5	Costs (€)	Comments
	Arms		·Minimum risk to operators/diver	·Requires additional technologies to move munitions to a disposal site		200 – 5000 High research & development cost	-Can remove human risk -Can inter shipwrecks and maneuver better than ROV/AUV's
	Blow-in-Place (Detonation)	S,M	-Quick and easy to perform -Disposal of large quantities of explosives	-Potential damage to local environment ·Harmful to aquatic life ·Increased risk to divers	4,5	500 – 5000 Daily	-Long term environmental impacts and health concern from toxin release into air, seabed and water

9. Companies and Organizations Performing Activities Related to Underwater Munition Remediation in Europe

Table 6 depicts the organizations that perform activities relating to underwater munitions. The information is thought to be as current as of present research, however, the information can change at any time.

Table 6 – Underwater Munition (or UXO) Management Organizations in Europe

Name	Base country	Visiting address	International phone number	Website	Services	Remarks
6 Alpha Associates	United Kingdom	14 Windmill Ave, Woolpit, Bury Saint Edmunds	4.42034E+11	6alpha.com	research; consultancy	
Adede	Belgium	Antwerpsesteenweg 56-60, Gent	3292286150	adede.com	survey, clearance; diving; guidance; research; consultancy	Head office
Adede	The Netherlands	Spoorlaan 322, Tilburg	31135452898	adede.com	survey, clearance; diving; guidance; research; consultancy	
Adede	United Kingdom	Hestercombe House, Cheddon Fitzpaine, Taunton	4.47951E+11	adede.com	survey, clearance; diving; guidance; research; consultancy	
Adede	Germany	Friedrichstraße 42-44, Köln	N/A	adede.com	survey, clearance; diving; guidance; research; consultancy	No phone number
Adede	Norway	Landsverkvegen 121, Nordagutu	4799522220	adede.com	survey, clearance; diving; guidance; research; consultancy	Branch area encompasses whole of Scandinavia
Bluestream	The Netherlands	Koperslagersweg 2, Den Helder	31223637784	bluestreamoffshore.com	survery; clearance; ROV; diving	
Bodac	The Netherlands	Hermalen 7, Schijndel	31735431010	bodac.eu	survey; clearance; research; consultancy	
Dynasafe	Sweden	Gammelbackavägen 8, Karlskoga	46586771270	dynasafe.com	demil systems	Head office
Dynasafe	Germany	Düsseldorfer Straße 138, Mülheim an der Ruhr	4.92085E+11	dynasafe.com	demil systems	
Dynasafe	Germany	Am Weiher 8, Langenselbold	4.96184E+11	dynasafe.com	demil systems	

Name	Base country	Visiting address	International phone number	Website	Services	Remarks
EIVA	Denmark	Niels Bohrs Vej 17, Skanderborg	4586282011	eiva.com	survey systems	Head office
EIVA	Germany	Klosterdamm 72, Delmenhorst	4.94221E+12	eiva.com	survey systems	
EIVA	United Kingdom	173 North Deeside Road, Peterculter, Scotland	4572170693	eiva.com	survey systems	
Explosive s.c.	Poland	Trakt św. Wojciecha 336, Gdánsk	48587630851	explosive.pl	clearance; consultancy; storage	
Fellows	United Kingdom	160 Ordnance Business Park, Gosport	4.48E+11	fellowsint.com	survey; clearance; research	
MACC International	United Kingdom	2 The St, Nacton, Ipswich	4.41474E+11	macc-eod.com	survey; research; consultancy	
MMT	Sweden	Sven Källfelts Gata 11, Västra Frölunda	46317620300	mmt.se	survey; chartering	Head office
MMT	United Kingdom	2A Banbury Office Village, Noral Way, Banbury	4.41296E+11	mmt.se	survey; chartering	
MMT	Norway	Garpeskjærveien 2, Haugesund	N/A	mmt.se	survey; chartering	
MUSC	United Kingdom	HQS Wellington, Temple Stairs Victoria Embankment, London	4.47802E+11	mandusc.com	survey; clearance; consultancy	
North Sea Service	Denmark	Morsøgade 4, Esbjerg	4560150840	ntseas.com	survey; clearance; diving; guidance	
Olympic Subsea	Norway	Holmsildgata 12, Fosnavåg	4770081200	olympic.no	chartering	
Ordtek	United Kingdom	Herz House Unit B21, Owen Rd, Diss	4.4138E+11	ordtek.com	survey; consultancy	
Patzold, Köbke Engineers	Germany	Ritscherstraße 5, Buchholz	4.94187E+12	pk-engineers.de	survey; guidance; consultancy	

Name	Base country	Visiting address	International phone number	Website	Services	Remarks
Planit	United Kingdom	N/A	4.48001E+11	planit-international.com	survey; guidance; consultancy; research	No visiting address
REASeuro	The Netherlands	Alphenseweg 4a, Riel	31135186076	reaseuro.nl	clearance; consultancy; research	
Risk&Co	France	38 rue Jacques Ibert, Levallois-Perret	33155242322	riskeco.com	survey; clearance; guidance	
RPS Explosives Engineering Services	United Kingdom	5 Queen Mother Square, Poundbury, Dorchester	4.41292E+11	rpsuxo.com	survey; guidance; consultancy	
SafeLane Global	United Kingdom	Phocle Business Park Unit 2, Phocle Green, Ross-on-Wye	4.41594E+11	safelaneglobal.com	survey, clearance; guidance; consultancy	Head office
SafeLane Global	Germany	Seestraße 35b, Ludwigsfelde	49337851900	safelaneglobal.com	survey, clearance; guidance; consultancy	
SafeLane Global - Marine	United Kingdom	The Courtyard Unit 3, Campus Way, Gillingham	4.41634E+11	safelaneglobal.com	survey, clearance; guidance; consultancy	
Seaterra	Germany	An der Trift 21, Wandlitz	4.9334E+11	seaterra.de	survey; clearance; chartering	Head office
Seaterra	Germany	Werkstraße 6, Seevetal	4.94106E+12	seaterra.de	survey; clearance; chartering	
Tauber	Germany	Virnkamp 26, Münster	4.92513E+11	munition.de	survey; clearance; research	
UXO Offshore Services	The Netherlands	Breedeweg 49, Castricum	31613909332	uxoos.com	clearance; consultancy; guidance; research; diving	
Vallon	Germany	Arbachtalstraße 10, Eningen	49712198550	vallon.de	survey systems	
Zetica	United Kingdom	Zetica House, Southfield Road, Eynsham, Witney	4.41994E+11	zetica.com	clearance; guidance; research	

10. References

Asahina, J. K. et al. (2012). How Safe is Safe Enough for a Chemical Weapons Destruction System? *The Marine Technology Society Journal*, *46*(1), 92-101.

Beddington, J. & Kinloch A.J. (2005). *Munitions Dumped at Sea: A Literature Review*. Imperial College London Consultants. London.

Beldowski, J., Long,T.P. *Chemical Munitions Search and Assessment Project-Towards Creating Risk Assessment Tools for the Baltic Sea*. *The Marine Technology Society Journal*, *46*(1), 30.

Bełdowski, J., Been, R. & Turmus, E.K. (2018). *Towards the Monitoring of Dumped Munitions Threat (MODUM): A Study of Chemical Munitions Dumpsites in the Baltic Sea*. Springer. Dordrecht.

Ford, G., Ottemoller, L., & Baptie, B. (2005). Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004. Edinburgh: British Geological Survey Commissioned Report, 1-15

Duursma, E.K., editor,(1999). *Dumped Chemical Weapons in the Sea -Options-(Synopsis).,*Dr. A.H. Heineken Foundation for the Environment, 19, 32-34

Greenberg, M.I. et al. (2016). Sea-Dumped Chemical Weapons: Environmental Risk, Occupational Hazard. *Clinical Toxicology*, *54*(2), 79-91.

Hart, J. (2000). 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.

Heaton, H., & Stock, T. (n.d). Recovered Sea-Dumped Chemical Weapons - possibilities for on- and off-shore treatment. *Underwater Munitions*. Consulted from http://underwatermunitions.org/wp-content/uploads/2016/03/Harley_Heaton_Recovered_Sea_dumped_CW.pdf

HELCOM (2013). Chemical Munitions Dumped in the Baltic Sea. Report of the *ad hoc* Expert Group to Update and Review the Existing Information on Dumped Chemical Munitions in the Baltic Sea (HELCOM MUNI). *Baltic Sea Environment Proceedings*, *142*.

Institute of Oceanology of the Polish Academy of Sciences (IO PAN) (n.d). Chemsea Findings. *Underwater Munitions*. Consulted from http://underwatermunitions.org//wp-content/uploads/2016/08/CHEMSEA_Findings_24.01.pdf

National Academies of Sciences, Engineering, and Medicine (2018). Alternatives for the Demilitarization of Conventional Munitions. Washington, DC: The National Academies Press. https://doi.org/10.17226/25140.

Nord Stream Report. (2010). *Background Information: Nord Stream and Munitions in the Baltic Sea*

Miller, P., *Abrasive Waterjets - A Nontradional Process for the Safe and Environmental Friendly Demilitarization of Underwater High-Explosive Munitions. Marine Technology Society Journal (46) 1, 83-89*

Peng, C., Zhao, X. & Liu, G. (2015). Noise in the Sea and Its Impacts on Marine Organisms. *International Journal of Environment Research and Public Health,* 12(10), 12304–12323.

Sanderson, H. et al. (2010). Environmental Hazards of Sea-Dumped Chemical Weapons. *Environment, Science, and Technology*, *44*, 4389-4394.

Stock, T., & Lohs, K., (1997). *The Challenge of Old Chemical Munitions and Toxic Armament Wastes*. Oxford: Oxford University Press.

Tornes, J.A., Voie, O.A., Ljones, M., Opstad, A.M., Bjerkeseth, L.H., & Hussain, F. (2002). Investigation and risk assessment of ships loaded with chemical ammunition scuttled in Skagerrak. Consulted from: http://www.miljodirektoratet.no/old/klif/publikasjoner/1907/ta1907.pdf

Underwater Munitions (n.d). Overview on underwater munitions technology and mythology for military munitions response programs (MMRP's). *Underwater Munitions*. Consulted from http://www.underwatermunitions.org/pdf/overview_MMRP.pdf