Agenda Item 4.6 | Review of New Information on Threats to Small Cetaceans

Underwater Unexploded Ordnance

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Underwater Unexploded Ordnance – Methods for a Cetacean-friendly Removal of Explosives as Alternatives to Blasting

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Underwater Unexploded Ordnance – Methods for a Cetacean-friendly Removal of Explosives as Alternatives to Blasting

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Fig. 1: Test detonation when using a bubble curtain

1. ABSTRACT

Old sea-dumped ammunition poses a threat to marine mammals and the environment. For cetaceans, the conventional ammunition removal by blasting is a particular hazard. High sound pressure and explosion-related shock waves can lead to severe injury and hearing impairment in marine mammals at considerable distance from detonation sites. Alternative techniques to render old ammunition harmless are available and in order to minimize harm to marine mammals detonations in the marine environment can be avoided in most cases. Advanced techniques for treatment of ammunition are presented comprising freezing, the use of robotic equipment, Water Abrasive Suspension cutting, disposal in a Static Detonation Chamber and photolytic destruction of explosive substances. If underwater detonations cannot be avoided, suitable mitigation measures need to be introduced. Test detonations demonstrated that it was possible to reduce the danger area by over 98 % when using a double bubble curtain.

2. INTRODUCTION

Cetaceans face serious threats from anthropogenic activities in many parts of the world. While some interaction with humans is well understood, the threat posed by blasting and the decay of underwater unexploded ordnance (UWUXO) has yet to be quantified.

Conventional ammunition has been discarded in waters all over the world. Dumping in coastal waters and on the High Seas represented a “quick and dirty” method to get rid of surplus material and problematic waste. In years following WW II almost no alternative to sea dumping and burying appear to have existed to demilitarise existing arsenals. Often, ammunition was dumped in transit to dumping sites. Sometimes, ammunition was relocated during fishing activities, thus making it difficult to locate and salvage dumped ammunition. Often, the history of UWUXO has been hidden to the extent that even the military possesses little information on the exact location of disposal sites, their contents and the risks they pose to the environment.

UWUXO is considered a hazard to humans when found during fishing activities, construction work or other marine activities. Ammunition shells start to decay in sea water releasing toxic explosive substances into the surrounding ocean, posing a threat to the marine environment. Underwater explosions, the conventional way to treat UWUXO, pose a serious threat to biota such as marine mammals (Richardson et al. 1995). Detonations are the strongest point source of anthropogenic noise in the marine environment. High sound pressure and explosion-related shock waves can lead to severe injuries and hearing impairment in marine mammals at considerable distance from the detonation site.

According to estimates, at least 500,000 tons of ammunition from World Wars (WW) I and II plus an unknown amount of modern ammunition from the Federal German Navy, the former National People’s Army of the German Democratic Republic, NATO and Soviet Navy activities still lie in German waters of the North and Baltic Seas (Nehring 2008). As a rule, located large ammunition items (mines, torpedoes, aircraft bombs etc.) are immediately labelled "danger in delay" by authorities and blown up as quickly as possible.

Recently, innovative ways of recovering and disposing of ammunition have been considered which would pose less of a threat to wildlife in the oceans. Many of these methods are already used while the development of others is advanced enough putting them to practical tests. These new methods have the potential of substantially reducing harm to the marine environment.

The main objective of this paper is to provide information on UWUXO primarily relevant to cetaceans. Our paper intends to provide an overview of danger posed by blasting, toxicology of explosives and alternatives to conventional ammunition removal by blasting.

3. THE GERMAN BALTIC AS AN EXAMPLE FOR A MARINE AREA WITH LARGE AMOUNTS OF AMMUNITION DEPOSITED

The former treatment of WW II ammunition located in the Baltic by way of explosion was questioned by German NGOs in 2006 after the discovery of a total of 130 large ammunition items (torpedo heads, ground mines, moored contact mines) and a number of small mines at two locations in the former ammunition dumping site "Kolberger Heide" (Kiel Bight). By that time 33 of the large items had already been blown up by the Explosive Ordnance Disposal of the Federal State of Schleswig-Holstein (SH) due to plans for re-routing a shipping lane.

According to old documentation, 8 000 torpedo heads and 10 000 mines among other things, were initially dumped at "Kolberger Heide" (Nehring 2007). Their whereabouts are unknown. Some of the ammunition was probably removed after the war by scrap metal seekers (Hofmann 1956) and on the occasion of the Olympic Sailing Competitions held in nearby Kiel in 1972. It appears to be essential to thoroughly investigate post-war records on the deposition of ammunition in order to obtain more accurate information. The same applies to the remainder of the Baltic region where no systematic search for the amount, location and condition of UWUXO has been conducted so far.

Removal of UWUXO generally takes place by way of explosion: if old ammunition is located and considered to form an immediate threat, the ammunition is blasted by attaching an explosive charge (usually contact donor-charges of 4 kg PETN, a military explosive) to the ammunition shell. Sometimes, the ammunition is pulled elsewhere before blasting in order to keep a safe distance to underwater structures or other ordnance items. Safety zones of several kilometres for swimmers, divers and boaters are installed and monitored by authorities.

4. DANGER OF BLASTING TO CETACEANS

Blasting creates several risks to marine mammals and the environment. The quick expansion of a gas bubble as a result of a marine explosion creates an immediate positive shock pulse followed by a series of positive and negative pressure changes in amplitude originating from the collapse of the bubble (Urick 1983). Such rapid pressure changes can cause injury in marine mammals (Richardson et al. 1995;review in: Minerals Management Service 2004). Most sensitive to pressure, ears of marine mammals are the organs most susceptible to injury (Ketten 1995).

Different sound velocities impacting on tissues of different densities can lead to severe physical damage such as laceration and rupture (Landsberg 2000). Blast effects are greatest in organs containing gas (nasal sacs, larynx, pharynx, trachea, lungs and gastrointestinal tract, or the middle-ear cavity in pinnipeds). Injury of these tissues can create air embolisms. Destruction of cetacean acoustic jaw fats can result in fat embolisms.

Blast over-pressure can result in haemorrhages in the brain and ears, and injuries in the middle and inner ear. A rapid increase in venous pressure caused by compression of the thorax and abdomen by the shock wave can lead to rupture of small blood vessels such as in the brain.

Another effect of explosions and other loud noise is acoustic trauma, i.e. damage to the cochlear structures caused by strong acoustic intensity. This effect can either be temporary (temporary threshold shift, TTS) due to physiological exhaustion of sensory cells or permanent (permanent threshold shift, PTS) due to loss of hair cell bodies and subsequent neuronal degeneration. The extremely short signal rise time in an explosion may immediately lead to PTS (Ketten 1995).

It is difficult to determine the distance at which physical injury, hearing impairment or disturbance occurs (Richardson et al. 1995). The range over which marine mammals can be impacted is dependent on the pressure level at the source, sound/energy radiation in the water, type of sea floor and specific thresholds for noise exposure. Southall et al. (2007) suggested dual[1] noise-exposure criteria for marine mammals. However, their recommendation for pulsed sounds cannot be transferred to explosions due to the much longer rise times created by seismic airguns, sonar or pile driving for which dual noise exposure criteria were developed.

The pressure from a shock wave, and thus the potential for injury depends largely on the charge weight and specific detonation velocity[2] (Urick 1983). Radiation and attenuation of the pressure wave depends on water depth, sediment, sea state, stratification of the water column, temperature, salinity and other variables.

Using an equation by Thiele & Stepputat (1998) based on experimental measurements and injury patterns of marine organisms during underwater explosions, safety distances for humans and cetaceans can be calculated. Based on a high probability of lethal or severe injury these radii are 1.7 km for swimmers, 4.3 km for divers and 2.8 km for harbour porpoises for a 350 kg explosive charge similar to those found in Kiel Bight. The PTS zone extends much further than this zone of physical injury. TTS can be assumed at an even greater distance (Koschinski 2007).

Underwater explosions are not always under the control of humans. Some explosive charges become very sensitive and volatile with age (cf. Bohn 2007). From seismograph data it was concluded that self detonations of deposited old ammunition has occurred in a trench off the Scottish coast (Ford et al. 2005). The matter of self-detonation is still being discussed in a controversial manner among experts.

5. TOXICOLOGY

A detailed assessment of risks to marine mammals and to the environment associated with dumping of ammunition is lacking. The long-term behaviour of chemical substances in ammunition is extremely variable and largely dependent on a

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[1] for peak-values and sound exposure level (SEL)

[2] modern explosives and old ammunition in a good condition detonate “high-order”, i. e. with a high detonation velocity (5,000 to 10,000 m*s-1 resulting in an extremely short rise time of the pulse) whereas aged explosives in some cases may “burn” with an unpredicted velocity which may be much lower (“low-order”)

number of different factors[3] (Hart & Stock 2008). This makes it extremely difficult to predict chemical reactions in water, sediment and biota at various stages of decomposition.

With ageing of the dumped ammunition, the risk of leakage of chemicals from UWUXO increases and becomes a matter of serious concern. Conventional explosives such as TNT, RDX and Hexanitrodiphenylamine spread into the marine environment. All of them and many of their degradation products are highly toxic and mutagenic to marine organisms (Won et al. 1976;LfULG 1998;Ek 2005). Heavy metals known to be contained in UWUXO (e. g., in fuses) are being dispersed. Some of these substances such as mercury have a high bioaccumulation potential. They are suspected of inducing adverse effects on the immune and endocrine systems in cetaceans (Strand et al. 2005).

MLUR[4] (2007) analysed water and sediment samples from "Kolberger Heide" for explosive substances and their typical degradation products. The highest concentration of TNT in a sediment sample was 7.1 $mg*kg^{-1}$ sediment. Strange enough this was compared to a limit considered to be safe for children's playgrounds of 20 $mg*kg^{-1}$ soil. This comparison shows the perplexity of some authorities when dealing with the effect of explosives on the ecosystem.

To date, no legal threshold levels exist for the marine environment. Barton & Porter (2004) measured a 2700-fold higher TNT concentration (19.3 $g*kg^{-1}$) next to a bomb and documented a declining trend with distance in concentration of explosive substances in the water, sediment and biota. A proper design of the sampling scheme appears thus crucial for the outcome of such studies. Francken et al. (2009) predicted an exponential decrease in TNT concentration in marine sediments with distance to ammunition items. Sedimentation, currents and redox equilibrium are other factors determining contamination with explosives and their derivates (Pfeiffer 2007a;DeCarlo et al. 2009).

Content of biota near UWUXO depend on the degree of mobility of the biota – with highest concentrations measured in sessile organisms (Barton & Porter 2004). Accumulation in biota, especially filter feeding sessile organisms, may be explained by dispersal of granular particles which are easily ingested. Toxicity originating from point sources may not be as relevant for highly mobile organisms such as cetaceans as it is for benthic invertebrates (cf. Ek 2005). Although the bioaccumulation potential of TNT and other explosives has not been sufficiently studied to date, there is no reason to believe that there is no effect on marine mammals. There is an indication that some of the biotransformation products of TNT (of which the toxicity is unknown) rather than TNT itself will be accumulated (cf. Beddington et al. 2005).

6. POSSIBLE ALTERNATIVES TO BLASTING

New developments in detection, evaluation, recovery and disposal of ammunition were presented at the symposium "New methods of ammunition removal in the North and Baltic Sea" (Kiel, Germany in 2007)[5], the „Conference of Chemical and

[3] temperature, pH-value, salinity, pressure, currents, chemical composition, corrosive activity, solubility, purity, stability and reactivity
[4] Ministry of Agriculture, Environment and Rural Areas of the Federal State of Schleswig-Holstein
[5] http://schleswig-holstein.nabu.de/naturvorort/meeressaeuger/symposium-englisch/

Conventional Munitions Dumped at Sea"(Halifax, Canada in 2007), or the Second International Dialogue on Underwater Munitions (Honolulu, Hawaii in 2009)[6].

6.1. Salvage operation using freezing techniques

Old ammunition is known to become unstable during recovery and transport and may leak when disturbed (Heaton & Frankovic 2009). One option for salvaging such ammunition is iced using liquid nitrogen or supercooling equipment (Mayer 2007, fig. 2). The ice encases the filling, provides a high resistance and thus stabilises and seals ammunition objects during treatment or transport. Using this technique, chemical reactions are decelerated and the risk of an unwanted detonation is lowered. Transporting iced ammunition to a locality where it can be safely deposited or removed, is conceivable. To further increase the stability and to retain the low temperatures using less energy it is possible to conduct this process in a detonation safe steel containment (Pfeiffer 2007b). Although insulation can provide some protection against thermal conduction, the high energy demand may restrict this technology to use in temperate and cold water environments.

Fig. 2: Ammunition salvage using freezing. Demonstration in the Baltic, © North Sea Divers, Ammersbek, Germany

6.2. Remotely operated salvage operation using robotics

The main objective of the use of robotics and remotely operated equipment is to minimize hazard to the people involved in the salvage. Several different salvage and transportation systems are commercially available, including remotely operated vehicles, lift bags or task specific robots (Schwartz 2009, fig. 3). Available systems have a flexible design and allow safe and precise handling of ammunition objects. They only need a small support team and can work around the clock. Due to their unlimited time of operation on the seafloor and applicability to great operation depth these methods are extremely cost effective (Coughlin 2009).

[6] www.underwatermunitions.com

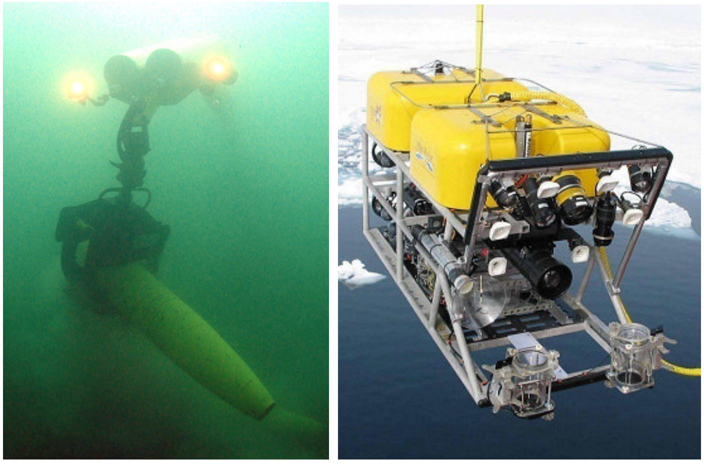

Fig. 3: Examples of remotely operated ammunition salvage systems © Underwater Ordnance Recovery, Inc, Norfolk VA, USA, © ARA Incorporated, Sykesville MD, USA

6.3. Apportioning and deactivating ammunition using jet cutting

Water Abrasive Suspension Jet cutting is a versatile method applicable to apportioning large ammunition, or to deactivate fused ammunition. Using remotely controlled jet cutting renders the explosion of old ammunition unnecessary. These advanced systems can cut precisely with a thin cut through rust, coral, concrete or steel in waters down to 600 m depth. Such treatment will not initiate explosion (Miller 2009). Robotic equipment (manipulators) is available for this technology (Eder 2007;Heaton & Frankovic 2009). Also for mines exhibiting dismantling barriers or bombs having degraded but still active fuses water jet cutting represents a secure alternative to blasting. Springs in mechanical fuses are simply severed and cables disconnected during cutting (Eder 2007, fig. 4). However, jet cutting may require the development of custom designed manipulators to cope with difficulties occurring in ammunition buried, piled up or covered in thick crusts.

Fig. 4: Defusing of a GP 500 bomb using remotely controlled water abrasive suspension cutting © ANT AG, Lübeck, Germany

6.4. In-situ ammunition destruction with Static Detonation Chambers

Some land-based technologies for treatment of old ammunition can also be applied to sea-dumped ammunition (Stock 2007, fig. 5). Static Detonation Chambers which allow a safe destruction and cleaned off-gas release are available as stationary and mobile units for 1 kg to 3 kg of explosives per feeding. All types of ammunition are safely destroyed in a Static Detonation Chamber at approximately 500-550°C. The feeding system can operate without personnel involved close to the plant.

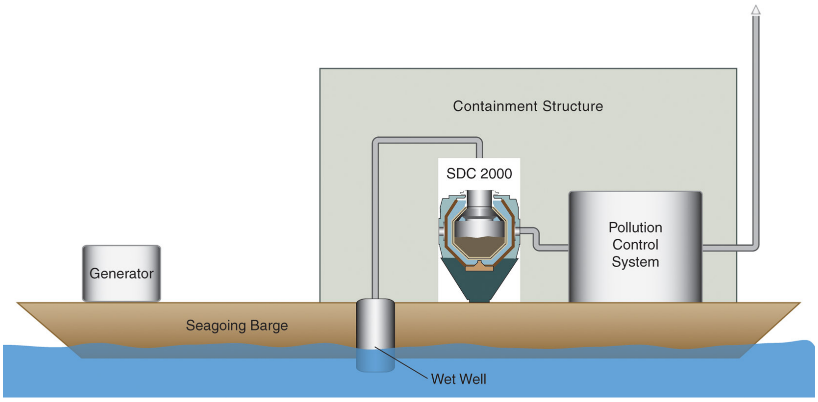

Fig. 5: Concept of an advanced underwater munitions destruction unit (© dynasafe Germany GmbH, Mülheim/Ruhr)

6.5. Photolytic Ammunition Removal

Photolysis is a common method to remove warfare-related organic substances from contaminated water. This method provides for the explosives contained in old ammunition on the seafloor to be flushed out with hot water and to be collected in a reservoir on a barge (fig. 6). The organic explosive substances are then removed from the water using photolysis allowing a quick and complete mineralization. In the laboratory, it was possible to remove almost all of the main components contained in old ammunition using UV light (Haas & Pfeiffer 2007). The addition of an activated carbon filter allows for residue-free destruction of explosives. Customary UV facilities have a capacity of up to 100m^3 per hour.

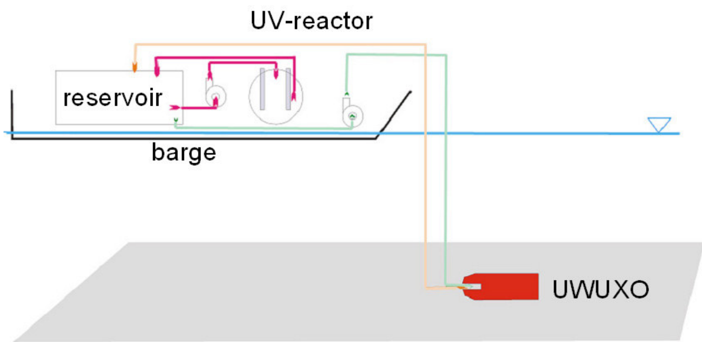

Fig. 6: Concept of a sea going photolytic treatment unit (Haas & Pfeiffer 2007)

6.6. Other methods

Schwartz (2009) lists a number of additional methods for recovery and disposal of ammunition. Currently, they do not seem suitable for treating large ammunition or pose additional threat to the environment. These include the use of an electromagnet or a dredge to recover ammunition items. For disposal of ammunition Low-Order Blow in Place (BIP) and entombment are added.

6.7. Combination of suggested methods

One method alone is not capable of removing UWUXO. Therefore, the some of the above-mentioned methods have to be combined. It will always require a case-specific decision to determine which methods can be used safely, are technically feasible, economical and effective. For example, composite explosives such as shooting wool no. 39[7] are particularly dangerous when in contact with oxygen. Such ammunition requires recovery and disposal when still wet. As a consequence, the combination of robotics, water jet cutting and a Static Detonation Chamber offers a safe and environmentally sound disposal technique (Heaton & Frankovic 2009). Alternatively, for photolytic treatment jet cutting can provide for holes to be cut into the shells in order to flush out the explosives.

7. MITIGATION DURING DETONATION USING A BUBBLE CURTAIN

The first priority when treating ammunition should be its recovery and safe disposal. If underwater detonations cannot be avoided, suitable mitigation measures for marine mammals must be taken. Sound and shock waves resulting from underwater blasting propagate almost undisturbed through water. Unlike air, water is incompressible and waves radiate much faster. In air, attenuation is much higher. Thus, sound attenuation within bubbly water is much higher than in water without bubbles due to the large differences in acoustic impedance of water and air (Nützel 2008).

Bubble curtains are walls of bubbles rising from a bottom-resting nozzle pipe connected to a compressor (fig. 7). A bubble curtain cushions the detonation by absorbing much of the energy of the blast and sound wave. Bubble curtains can effectively reduce the sound pressure and the shock wave (Nützel 2008, see chapter 8.1.). Bubble curtains can thus substantially reduce the danger zone for cetaceans and other marine organisms. Bubble curtains and physical barriers have been successfully utilized to protect rare or commercially valuable fish species from underwater detonations. Bubble curtains are thus recommended by some natural conservation agencies in the US in cases when blasting activities are being conducted (Keevin et al. 1997;Keevin 1998).

In order to build up an effective bubble curtain, knowledge of the development and behaviour of underwater bubble formation is essential (Wreth 2007). Important parameters when creating an efficient bubble curtain are:

- Air pressure of the supplying compressor
- Volume flow rate of compressed air
- Shape, arrangement and number of nozzles per metre of nozzle pipe
- Nozzle/bubble diameter

However, one must keep in mind that bubble curtains do not prevent harmful substances from entering the environment when an incomplete combustion of explosives occurs (see: chapter 8.2.).

Bubble curtains have a number of disadvantages and limitations (Keevin et al. 1997). They require optimisation to be used more widely in the future. It often proves to be difficult to deploy the pipes when the supporting vessel drifts due to wind or currents. Also, moving the bubble curtain system to a new location after each blasting operation may be complicated. For large explosive charges the air flow needed requires big compressors and an adequate power supply. When ammunition is blown up close to the coast, a fixed pressure pipe from land may be considered. Present designs of bubble curtains are quite costly which deters authorities from making them mandatory.

[7] 45% TNT, 30% Ammonium nitrate, 20% Aluminium, 5% Hexanitrodiphenylamine

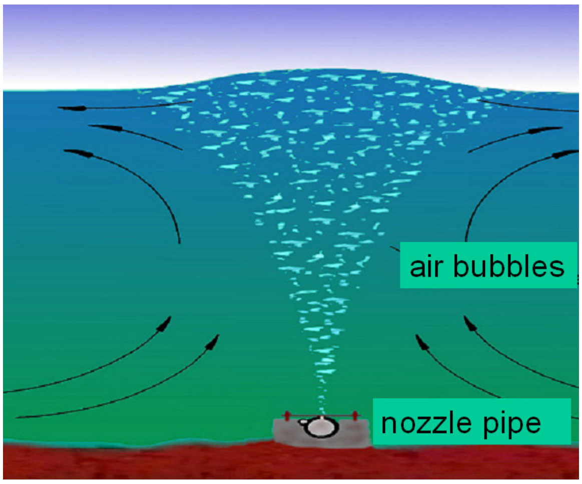

Fig. 7: Bubble curtain © Hydrotechnik Lübeck

8. RECENT DEVELOPMENTS IN GERMANY

Subsequent to an initiative by three German NGOs[8] to ban underwater detonations the Department of Disaster Management of the SH Ministry of the Interior has promised to carefully examine alternative suggestions to underwater detonations.

8.1. Use of a bubble curtain to reduce shock wave during blasting

The Federal Armed Forces Underwater Acoustics and Marine Geophysics Research Institute (FWG) investigated means of reducing the shock wave of underwater detonations (Nützel 2008). The efficiency of various bubble curtain configurations (single, double, triple) were tested with control detonations (1 kg charges). The best result was obtained using a double bubble curtain (at 4.75 and 5.75 m distance from the detonation, an air volume flow rate 20 m^3*min^{-1}), where a mean attenuation of 15.4 dB was achieved. This design would reduce the danger zone by over 98 %.

A single and a triple bubble curtain with the same air volume flow were less efficient. A single bubble curtain with a reduced air volume flow rate was the least efficient. A triple bubble curtain could work more effiently if the spacing between rings was increased to a value larger than the acoustic wave length of the spectral maximum (3 m at 500 Hz in the case of test detonations). When larger charges are used the diameter of the bubble curtain and the air volume flow have to be increased. The distance must be large enough to prevent the detonation gas bubble from destroying the bubble curtain.

8.2. Use of absorption samplers during test detonations

An underwater explosion represents an incomplete transformation of explosive material, i.e. there is no full conversion of reagents. Various potentially toxic reaction products are spread into the marine environment (BfUS 2008). Activated carbon samplers (‘passive samplers’) were deployed around a test detonation site of 10 small (charge weight 14 kg, shooting wool No. 39) WWII mines. Passive samplers can be used to collect post-detonation substances from fluids or gases. TNT, but no derivates, was detected near the surface up to 100 m downstream of the submarine explosions. The detected remnants indicate an incomplete transformation of the shooting wool, possibly leading to local contamination.

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[8] Nature and Biodiversity Conservation Union (NABU), Society for the Conservation of Marine Mammals (GSM), Society for Dolphin Conservation (GRD)

8.3. Tests of underwater jet cutting

Water Abrasive Suspension Jet cutting tests have been conducted with gypsum-filled bombshells on land and under water. Tripod-mounted and ring-shaped manipulators to be directly attached to the bombshell were tested. Results of these tests were promising. However, handling of ammunition items in the mud or in a stack of dumped UWUXO requires an optimised design of manipulators. Further, this treatment may reduce the visibility needed for remotely operated techniques by resuspension of sediments limiting the use of video and other sensors needed to handle robotics safely.

8.4. New administrative instruction regarding harbour porpoise protection

In the Federal States of Schleswig-Holstein and Mecklenburg-Prepomerania a new administrative instruction came into effect in 2008. The following measures are expected to ensure that harbour porpoises and other marine mammals leave the area of immediate danger well before detonation:

- Deployment of a ring of pingers (AquaMark 100) around the detonation site (spacing 200 m) before preparations for explosion
- Deployment of an acoustic seal scaring device 1 hour before detonation (exception: for the protection of EOD divers the seal scaring device is deactivated during dives)
- 15 min before detonation a scaring explosive of 10 g PETN will be fired (the scaring explosive must be deployed above the sediment)
- 5 min before detonation a scaring explosive of 20 g PETN will be fired

9. RESEARCH AND DEVELOPMENT NEEDS

Specialized salvage methods and equipment need to be developed or existing technologies adapted for use in coastal waters and on the High Seas. The technological basis is available. Photolytic destruction of organic explosives needs further development and tests before it can be considered operational for removal of large ammunition. Optimised manipulators for water jet cutting systems as well as flexible encasement methods during cutting must be developed to avoid dispersion of explosive filling when apportioning large UWUXO items.

If underwater detonations cannot be avoided a concept to protect marine mammals and other marine biota should be developed including the following components:

- no underwater detonations at times and in areas critical for marine mammals (reproduction, migration, large density areas etc.);
- no underwater detonations in or close to MPAs;
- implementation of mitigation measures to minimize risk to marine mammals (e. g. by using bubble curtains);
- development of an appropriate observer and acoustic monitoring scheme;
- deployment of suitable deterrents to prevent marine mammals from entering zones of danger, and
- determination of safe exposure levels for marine mammals.

Further research on the function of bubble curtains is needed in order to optimise bubble curtain design for use in marine detonations. This should comprise the design regarding diameter, bubble size and air flow relative to charge weight.

Research on the spreading of substances contained in ammunition in decay needs to be initiated. Risks associated with relocation of ammunition as a result of drift and anthropogenic activities have not sufficiently been addressed. The state of decay of ammunition dumped into the sea needs further investigation as a basis for developing decontamination concepts.

Investigations on chemical processes induced by explosives and related substances and their ecological effects should be undertaken. Toxicologists have long been demanding that comprehensive investigations and monitoring activities be conducted at dumping sites concerning a potential accumulation of TNT and its derivates and other explosives in mussels and in the sediment.

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