OVERVIEW ON UNDERWATER MUNITIONS TECHNOLOGY AND MYTHOLOGY FOR MILITARY MUNITIONS RESPONSE PROGRAMS (MMRP's)

1.0 INTRODUCTION

This document is not intended to identify all existing technologies and methodologies for underwater munitions response programs but provides a brief overview of some technologies and approaches that are or could be employed to address most aspects of underwater munitions response programs. A source for the exchange of information concerning underwater technologies can be found at the International Dialogue on Underwater Munitions website at www.underwatermunitions.org.

Additional information on MMRP technologies and other responses are included in the 2011-2012 issues of the Marine Technology Society Journal (MTSJ), titled: The Legacy of Underwater Munitions Worldwide: Policy and the Science of Assessment, Impacts and Potential Responses. Information can also be found via national and international recognized programs on standard and processes with organizations such as the US Army Corp of Engineers (USACE) and Canadian Department of National Defence (DND) UXO Legacy Site Program.

The main obstacles for detection, intrusive and non-intrusive investigations and remediation of shallow to extremely deep water munitions sites has been the education of responsible agencies that the technologies exists. The existence of existing technologies in the field of underwater oil and gas exploration is a perfect example of the development and fielding of technologies that can be utilized to locate, identify, and remove munitions located at depths ranging from shallow to extreme depths. Such advances in underwater technologies have reduced the costs associated with underwater operations. In recent years, the costs of working underwater have come down as fast as our ability to meet sub-sea challenges has gone up. In many cases, the oil and gas industry, as it searches for rich mineral deposits, has paved the way with new technologies that provide the basis for development of a whole new industry capable of investigating and, when required, addressing most aspects of underwater munitions safely and remotely. Recently governmental agencies such as the U.S. Army Corps of Engineers (USACE), U.S. Navy and the National Oceanic and Atmospheric Administration

(NOAA) in the United States and a wide assortment of governmental agencies in Europe and Asia are now actively developing these technologies.

The ability to locate and conduct site characterization is an extremely important first step in this process. 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. 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.

2.0 MILITARY MUNITIONS RESPONSE PROGRAMS (MMRP'S)

MMRP programs are designed with emphasis on safety and control by implementing a strong Project Management Plan that includes but not limited to: Project Management, Quality Management Plan (Quality Controls - QC and Quality Assurances - QA), Safety Management Plan (Health and Safety), Project Reporting and Project Close-out. These programs could be models or guides for the future development of a country's national munitions response program.

To completely understand the development of a MMRP program, it requires codification of a series of procedures and regulatory requirements. The Military Munitions Response Program (MMRP) was established in September of 2001 by the Defense Environmental Restoration

Program. It was established to identify and respond to environmental and explosive safety hazards posed by Munitions and Explosives of Concern (MEC) and Munitions Constituents (MC) at "surface" closed, transferred or transferring ranges. At the time that the MMRP was established underwater sites were excluded and the U.S. Department of Defense (DoD) refused to include underwater sites. Since 2001 gradually DoD has modified the rules concerning what constitutes a Military Munitions Response Site under the Military Munitions Response Program.

The current the United States DoD MMRP policy concerning underwater munitions response sites states if the site is deeper than 120 ft (36.57m), it is not considered an underwater munitions response site requiring remediation, and if the site is "dry" at low tide, then the site is a terrestrial munitions response site. The current guidance also states a site cannot be designated a munitions response site if the site is:

- Part of, or associated with, a designated operational range (terrestrial or water)
- A designated water disposal site
- A Formerly Used Defense Site (FUDS)
- A result of combat operations
- A maritime wreck
- An artificial reef

While the U.S. Military Munitions Response Program does provide a good working example, it does present some constraints. It limits the depth of a site to 120 ft. (36.57m) and it does not address disposal sites. There are also some questions regarding the exclusion of sites involving combat operations and maritime wrecks. The development of a truly responsive Munitions Response Program must address the concerns of both conventional and chemical munitions, at all depths. It must also all inclusive, utilizing a risk based approach.

2.1 Charter Document

One of the first steps in developing a MMRP is the charter document. The development of a charter document must be scientifically comprehensive, and address the concerns of both government agencies and the public.

Before a charter document can be developed, standardization of terminologies must be achieved to enable a clear understanding of both technical terms and data. It is important that all parties involved in the development of a MMRP charter document are able to use terms that are readily identifiable and clearly understood. The development of a MMRP charter document will require a multiple phase approach that includes a world-wide inventory of underwater site locations and an acceptable remediation program that is risk based.

2.2 Historical Review

Prior to commencing project activities a historical review should be carried out to determine what has transpired in the study area in the pass to present day. Historical reviews are conducted to gain a better understanding of what has transpired in order to better understand project requirements such as scope, risk and approach.

Historical reviews are normally carry-out in two phases and are determine by the amount of reliable and existing information available and the complexity of the site for the proposed project. Historical reviews help stem the loss of information and can provide a guide or bases to forum an understanding of what has transpired at the site.

The first phase is a desk top study that can be done by researching information from the public domain such as websites, libraries and available historical documents. Desk top studies are normally completed from 1 to 14 days.

The second phase is a detailed historical review that collects detailed information that will be used to develop a physical footprint for a munitions response site. Access to military and government documents is essential to this task and poses one of the hardest problem to overcome during any historical research. To successfully accomplish any research effort governmental approval and support must be established prior to any attempt to conduct a research project.

Once governmental approval is granted the next step is the development and staffing of the research team. Ideally the team should consist of technically qualified personnel with knowledge of munitions and a background in archive research techniques. Additionally procedures such as the development of information search/recovery protocols must be established prior to conducting the research. At a minimum a research team must have laptop computers connected to flat screen digital scanners, with large screen capabilities.

3.0 PLATFORMS

There are a variety of surveying 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. It is this variety that will be addressed below. “The challenges of conducting an underwater munitions detection survey include the properties of the water, the need to maintain safe working conditions, and the ability to accurately locate and retrieve the detected items”. The ability to detect underwater anomalies is at best a difficult undertaking, made more difficult as the depths increase. The evolving dynamics of the oceans themselves must also be considered. Underwater currents, marine growth and the effects of shifting bottom conditions only increase the problems one faces in trying to locate and recover material that has been deposited on the ocean floor decades ago. No one tool or one particular method can be successful in this effort. One can only view the efforts of the oil and gas exploration corporations and various Oceanography institutes to understand this dilemma.

3.1 DIVING

Divers may use either SCUBA (Self-Contained Underwater Breathing Apparatus), supplied air or one atmosphere suits. Each option has its advantages an 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.

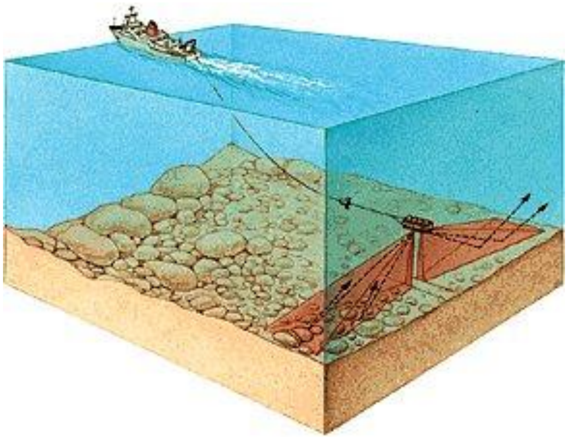
SCUBA divers can utilize either normal air or various gas mixtures. The use of normal compressed air allows SCUBA divers a limited amount of time and depth. While using normal air the diver is limited to approximately 30.48 meters and is limited to the amount of air that he can carry. A surface supplied 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 meter. At that depth, the bottom working time is limited to approximately 30-minutes.

At depths greater than 91.44 meters Saturation Diving is used which allows deeper dives and more ambitious underwater tasks. 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.

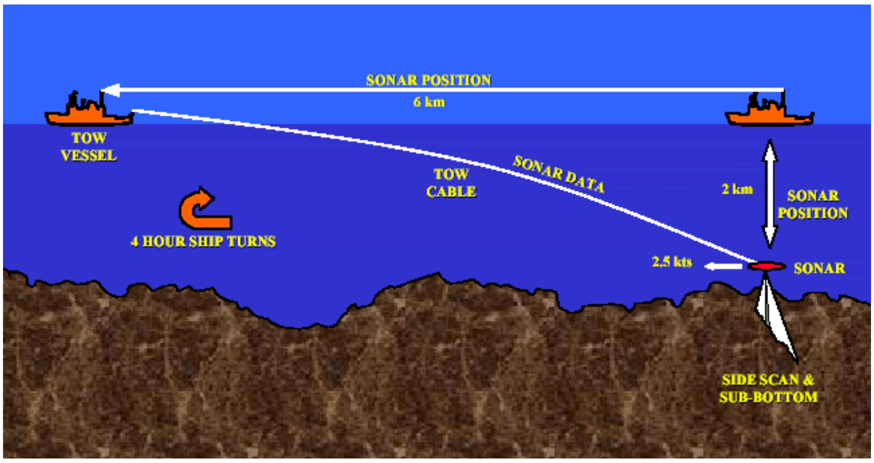
The Deep Diving System consists of a Deck Decompression Chamber (DDC) mounted on a surface-support ship. A Personnel Transfer Capsule (PTC) is mated to the DDC, and the combination is pressurized to a storage depth. Two or more divers enter the PTC, which is unmated and lowered to the working depth.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

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 metres. 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 meters 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.



3.2 UNDERWATER TOWED VEHICLE

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.

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.

3.3 AUTONOMOUS UNDERWATER VEHICLE (AUV)

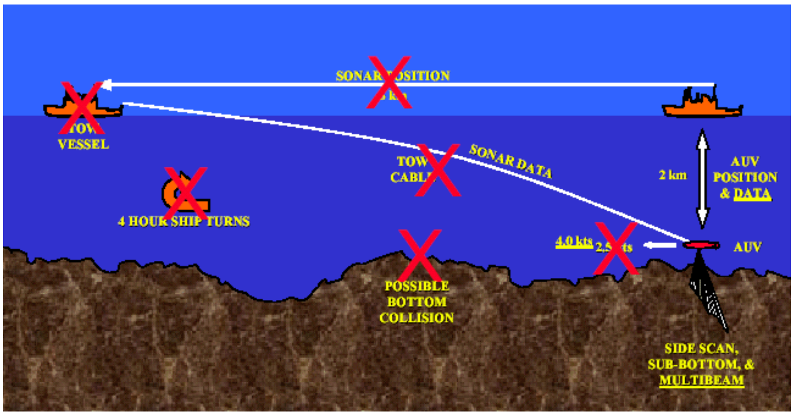
AUVs are unmanned or robotic vehicles that are using state-of-the-art technology to bring new capabilities to work in the subsea environment. In the past 30 years, nearly 200 AUVs have been built. Most of these systems have been experimental. However, they have achieved impressive results and this record of success is creating a demand for their use in operational settings.

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 maintain costs. They are employed today with many of the Worlds Navy's for Mine and Counter-Mine (MCM) measures for detection, mapping, recording and tracking of underwater munitions and munitions debris in real-time.

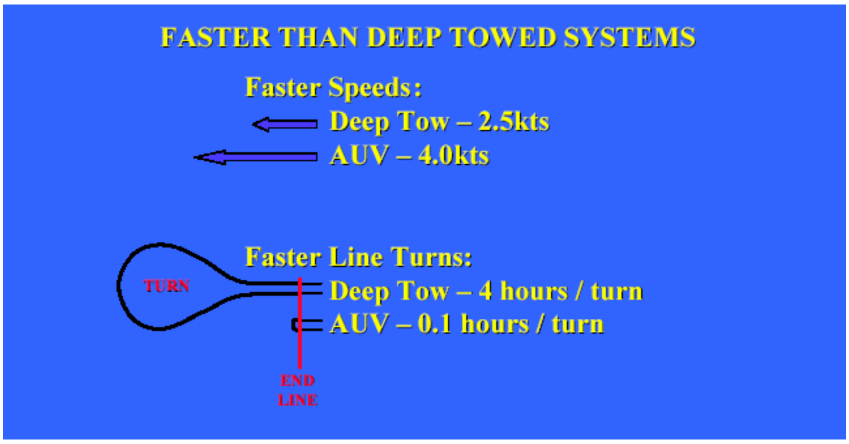
AUV’s are cost effect! First, only one vessel is required. The AUV mother ship, transits directly over the AUV (just like the "chase boat" tracked over the towfish). Cost and logistics are reduced substantially when the tow vessel, tow cable, winch, etc. are eliminated.



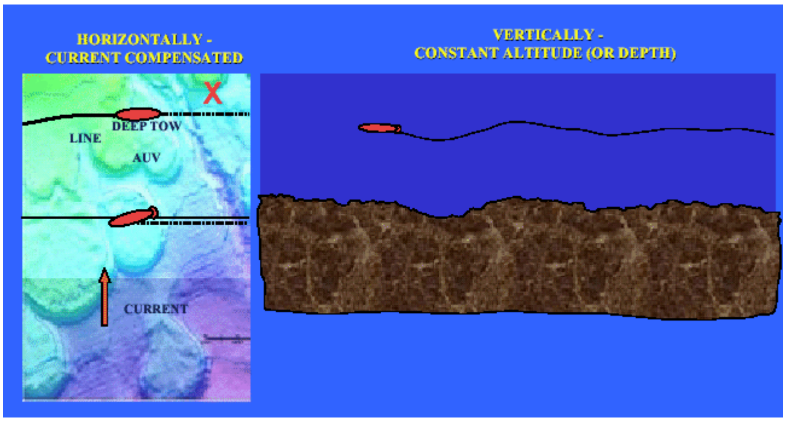
The survey time with the AUV is dramatically reduced over conventional towed systems in two ways:

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.

When an AUV is used instead of a deep towed platform, the project is greatly simplified. First, only one vessel is reqired. 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. The AUV may crab just a bit to overcome the currents, however, it will stay within a few meters of the programmed line. 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.

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

3.4 REMOTE OPERATED VEHICLES (ROV's)

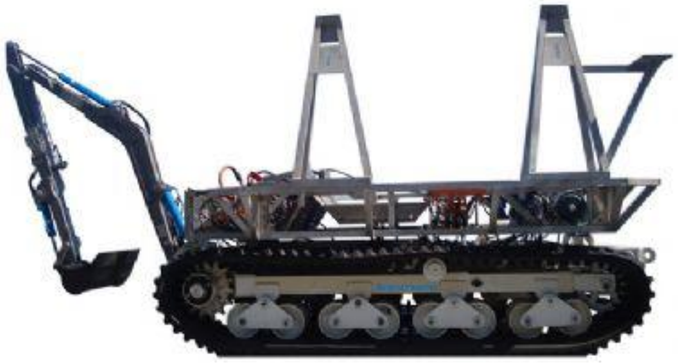
ROV is unmanned. However, it is "remotely piloted" and requires an operator on the remote console at all times. Instead of being self-sufficient like the AUV, a cable links it to a remote control console on the surface. Both electric power and control commands are sent down this cable (sometimes called an umbilical), and data from the vehicle's television cameras and sonars is sent up the cable. As is the case with the submersible, vertical and lateral thrusters are provided in addition to those needed for propulsion and the ROV is highly maneuverable. 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.

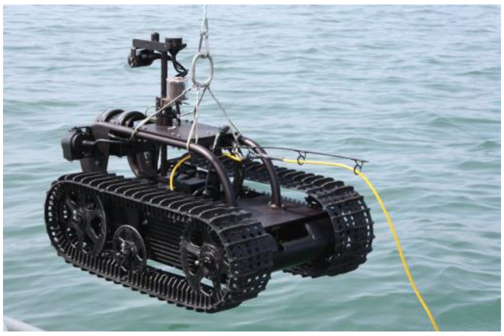
The umbilical is one of the vehicle's biggest assets, and at the same time, one of its biggest drawbacks. Because the ROV is physically connected to the surface, large amounts of power can be sent to the vehicle and large amounts of data can be received. Working against this, however, is drag on the 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 ROV's is beneficial.

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. 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.



3.5 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.

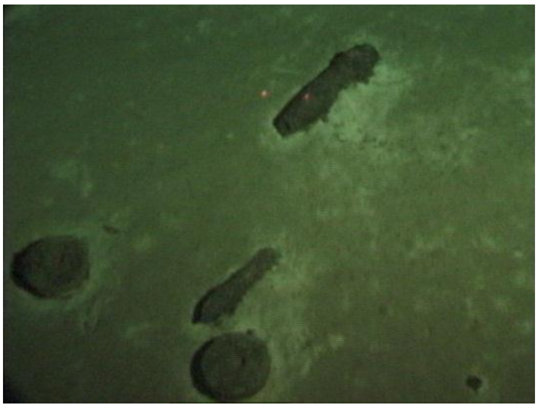
However, submersibles with trained experienced observers can dramatically increase survey swath widths and detection capabilities. The human eye is by far the most efficient visual survey tool currently available. Submersibles with trained observers are significantly better at surveying bottom features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

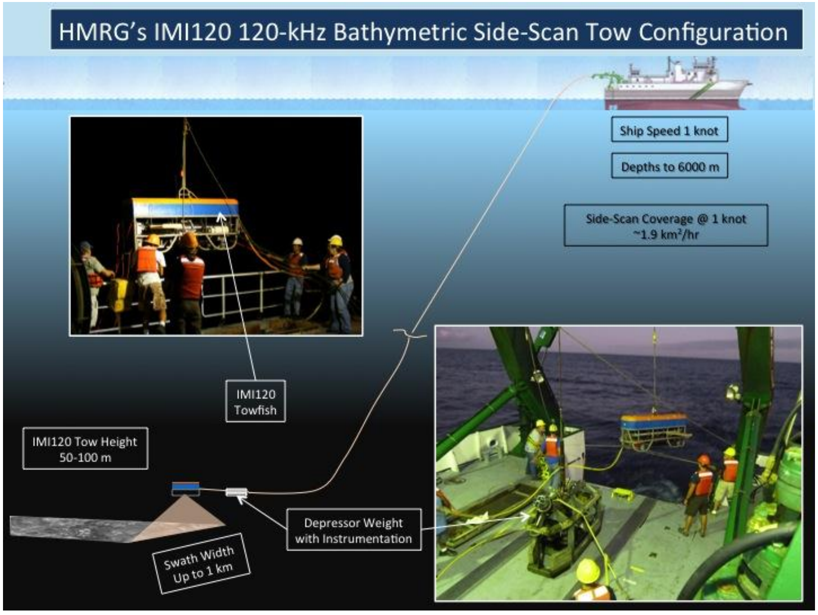
In the 1970's submersibles were used extensively by the military, the offshore oil industry and scientific research agencies. However, the rise of the ROV allowed much of the work previously done by submersible to be conducted at lower costs and today submersibles are used principally for scientific research. Fewer than 20 submersibles are remain in operation, with most being used by major oceanographic institutes. The University of Hawaii http://www.soest.hawaii.edu during their yearly certification dives with their two submersibles, the Pisces IV and Pisces V off the coast of Oahu near Barbers Point began observing large amounts of military munitions of various sizes and types. Munitions were scattered along the entire length of a drop-off that reached 1,652 meters in depth. Attempts were made to notify proper military authorities to no avail until newspaper articles in October of 2005 brought to the attention to the public and U.S. Congress the fact that toxic chemical munitions had been dumped in and around the Hawaiian Islands. At that time the discoveries that had been made years ago became a point of serious concern by the U.S. Department of Defense. The series of newspaper articles also spurred the U.S. Department

of Defense to begin a limited research effort to discover documents and records on where and how much had been dumped in the ocean around the Hawaiian Islands. Research that was conducted indicated that the disposal site that was discovered by the University of Hawaii during their testing programs did not contain any toxic chemical munitions, only conventional munitions. Photographs of the conventional munitions indicated that for the



most part the individual items of ordnance are in very good condition. While these finds were accidental, their discovery has provided an important insight as to the actual practices that occurred at the end of WW-II.

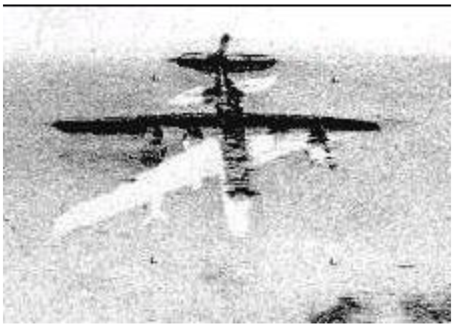
4.0 SURVEY DETECTION (WIDE AREA AND LOCALIZED)



Development and improved 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, EM 1002 multibean 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 haft 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.

4.1 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.

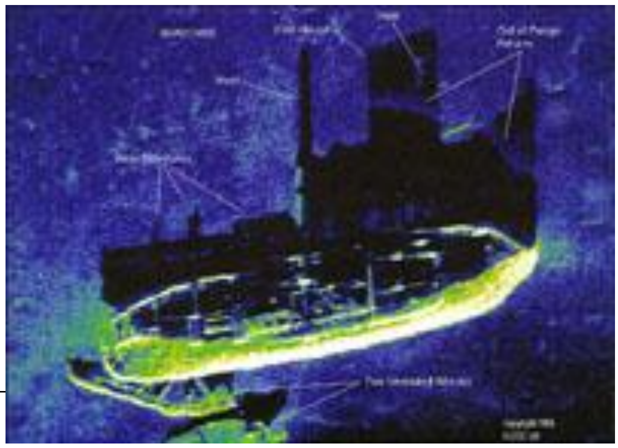
To meet the demands of "seeing" further underwater, engineers have turned away from the visible light spectrum and to another form of transmittable energy underwater: sound. Sound is also attenuated in the dense water environment, but not over as short a distance as light. Although the resolution of 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

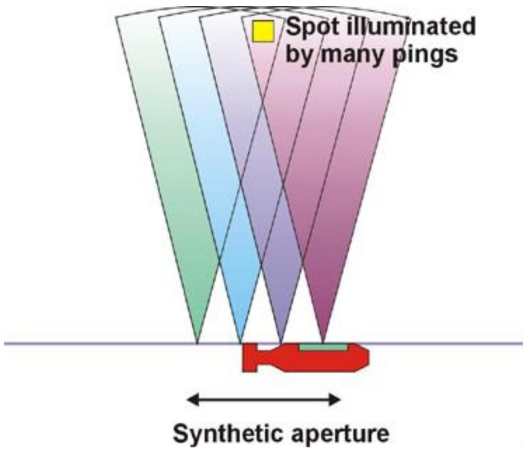


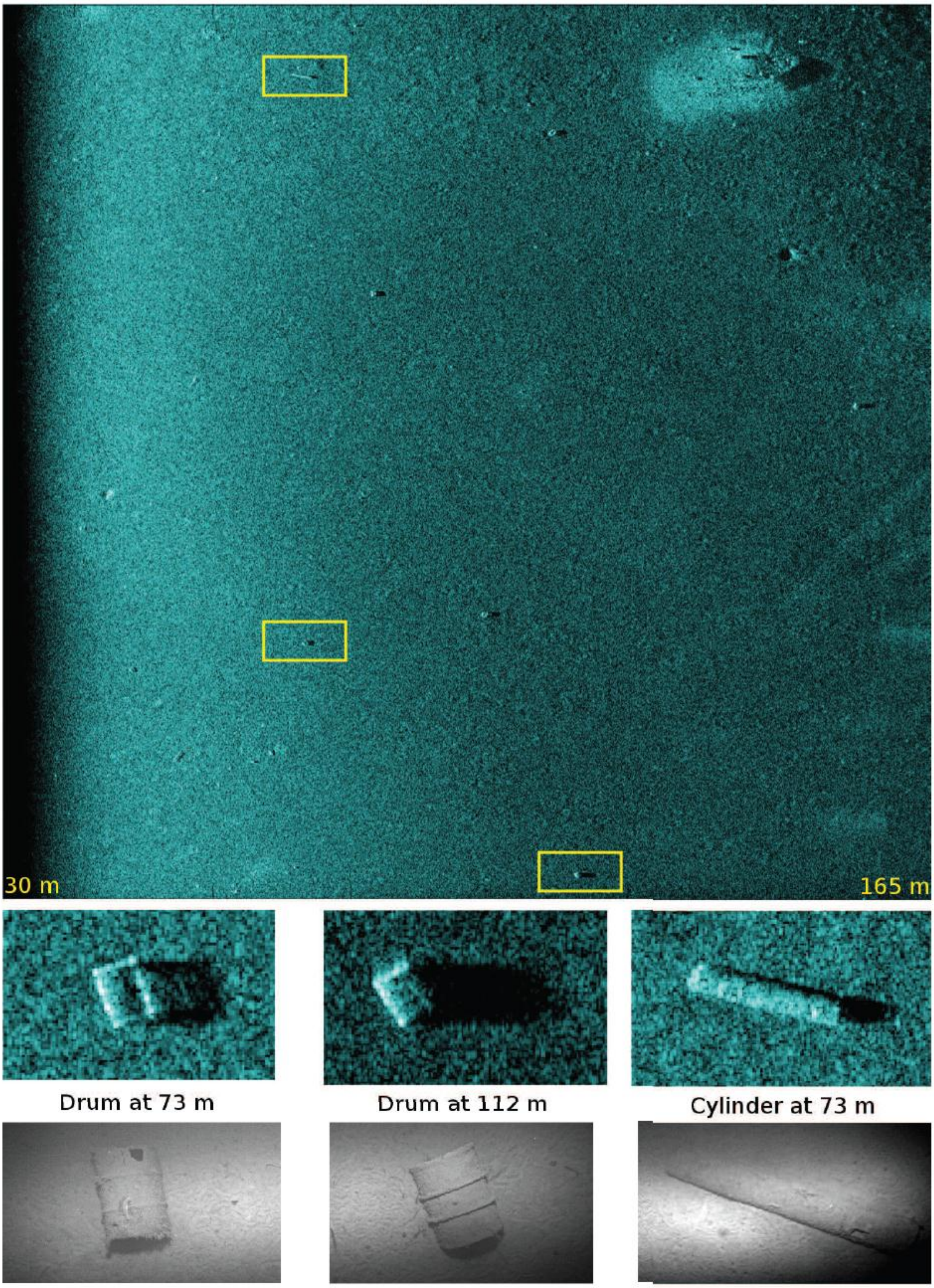
range of the low frequency comes into play. A vehicle may have more than one rotary scan sonar mounted on it. Two frequencies on two sonar heads working simultaneously, for example, will give a pilot a rapid informational update for targets and terrain on both high resolution and long range.

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.

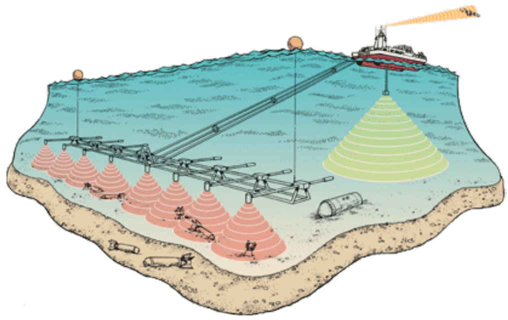
4.2 SYNTHETIC APERTURE SONAR (SAS)

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 sidescan sonars. 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. An example of the level of image resolution can be seen on the next page.




30 m
165 m
Drum at 73 m
Drum at 112 m
Cylinder at 73 m

4.3 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. 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.

4.4 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 wide spread in the surface UXO community. Terrance P. Long, President, Wentworth Environmental Inc., 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.

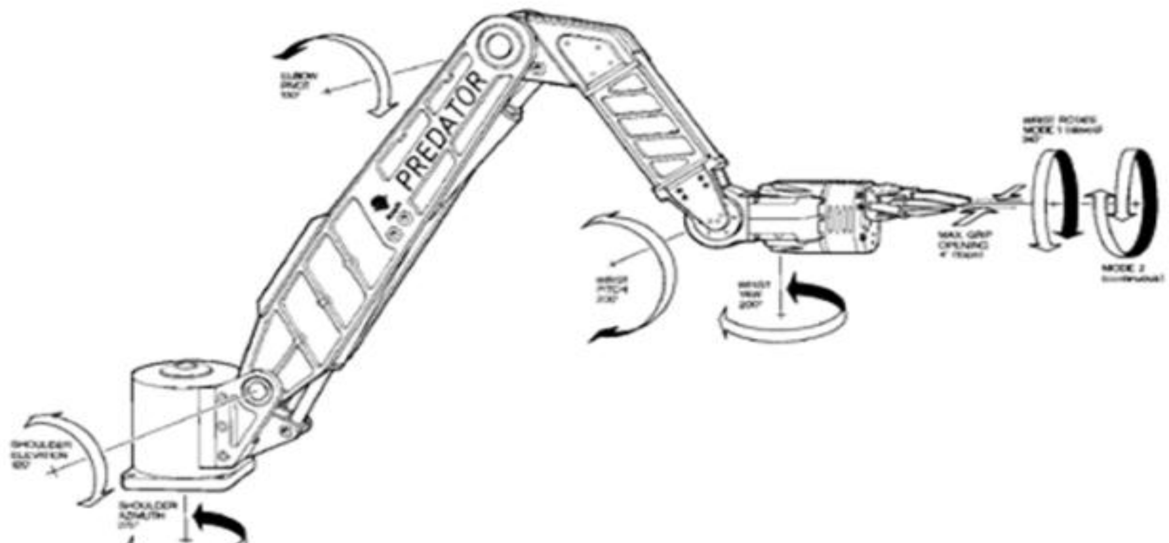
5.0 MANIPIULATORS

The front end of the vehicle is almost always the "business end." It is fitted with manipulators for performing work, and TV cameras, lights and sonars so operators can see to navigate and conduct the work operations assigned. Because the underwater environment is intrinsically inhospitable to humans, using remotely manipulated mechanical arms is a natural way to perform subsea work. Remote manipulation (also called teleoperation) allows human operators working from the surface to manipulate underwater objects. A teleoperated manipulator is not the same as a factory robot that repetitively performs a single assigned task or set of tasks under controlled conditions in a structured environment. Instead, a telerobotic manipulator is the mechanical equivalent of human arms and hands. It manipulates objects under direct human control in real time (that is, while the task is being performed) and can therefore function in an unstructured

environment. 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

Manipulator designs have improved dramatically over the years, integrating effective ergonomics along with power, dexterity and control. They have become easier to operate



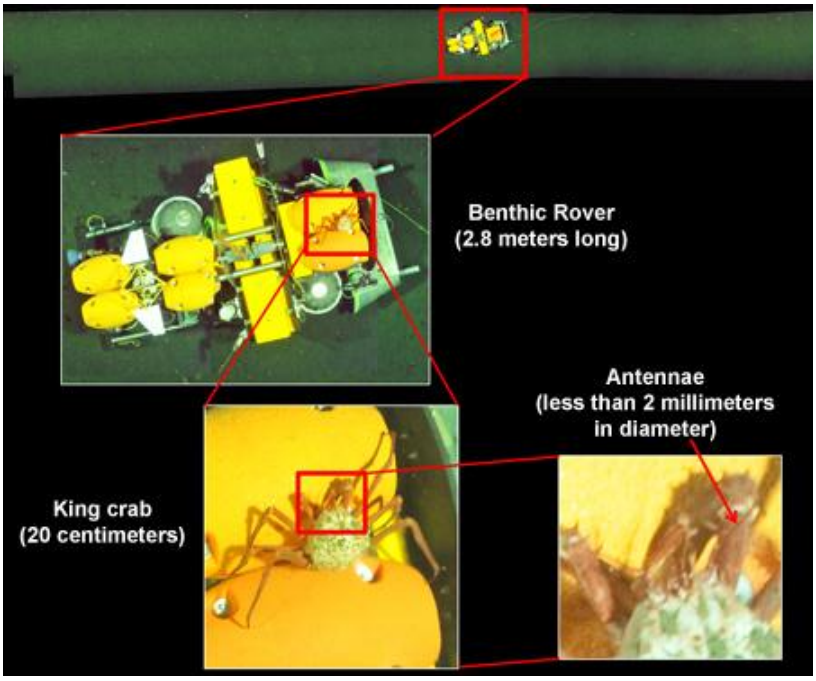
and maintain and have incorporated space-age technologies that have increased their reliability. Manipulators can be found in various configurations, degrees of freedom, and end uses are available in manipulators that are on the market today such as the *Orion* 7-function manipulator, developed by Schilling 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.

6.0 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-rov's 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 ROV's 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.



7.0 ENVIRONMENTAL SAMPLING

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 profiler's. Underwater vehicles can also be fitted with environmental sensors for bathometry 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.

Alterative 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 WW-I 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 rip-rap 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.

8.0 REMEDIATION/DISPOSAL

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 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.

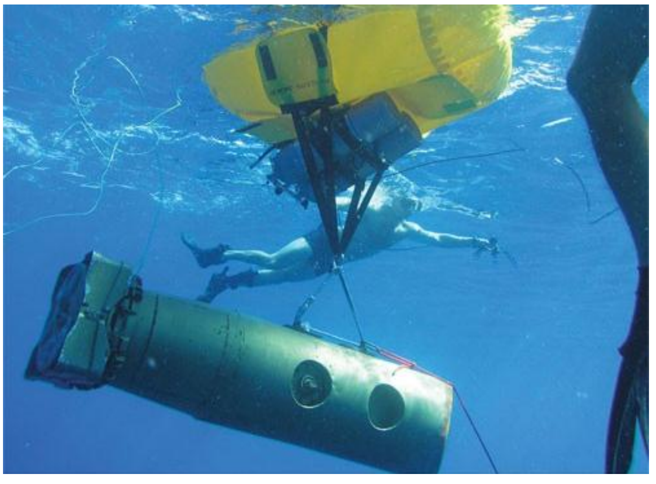
Containment could be accomplished through placement of an inert covering material to prevent or slow the corrosion of the CWM and release of the CA. It is also possible for the materials used for containment to include a reagent capable of degrading the CA.

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 assuring 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.

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. 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 sea floor 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 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 munitions from underwater locations. An example of the information contained in this report is the Kokkola Channel Project.

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.

The ESTCP report along with its sister agency the Strategic Environmental Research and Development Program (SERDP) has shown that recovery technologies do exist and that a wide range of companies are in a position to use those technologies.

After the safe and environmentally appropriate recovery of hazardous munitions has been accomplish, the next challenges is the safe disposal in a manner that does not harm the environment.

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.

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: "The process uses a detonation chamber in which chemical munitions are destroyed when donor charges surrounding the munitions are detonated. Off-gases are produced that require secondary treatment….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 particulates 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. 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

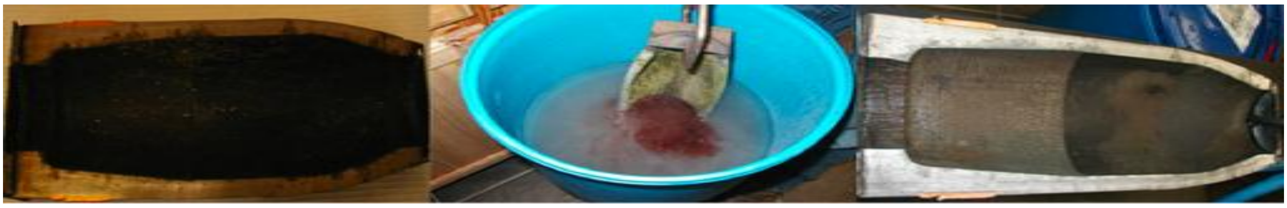
treatment system includes a cyclone for removal of large particulates and a thermal oxidizer/ or flameless thermal oxidizer that converts remaining organic materials to carbon dioxide and water. This is followed by a fast quench system to minimize dioxin and furan formation, acidic and basic (caustic) 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 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.”

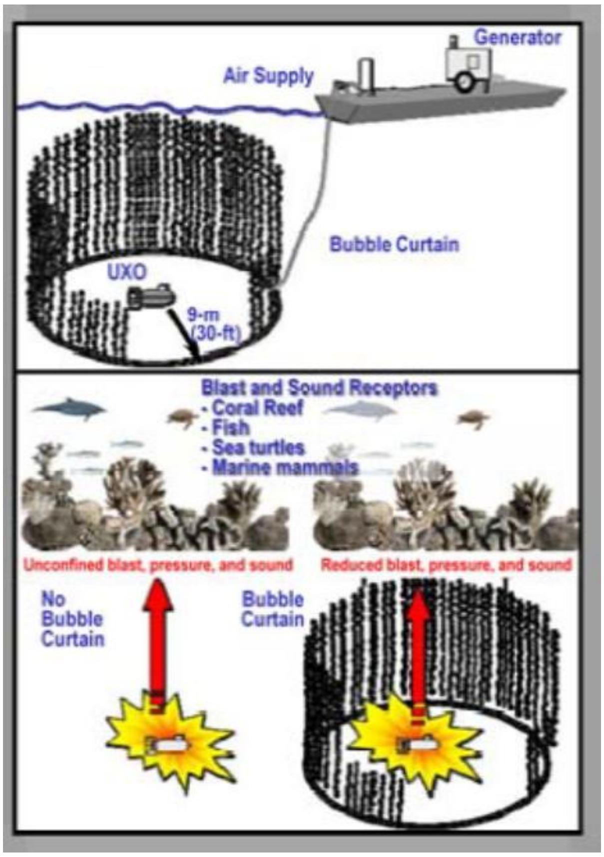
These systems may need to be adapted to address the specific needs relating to recovered underwater munitions, but they are accepted by regulatory agencies and are already operating at terrestrial sites in the EU, China, Japan, Germany and the United States.

A very good example of this existing technology is Kobe Steel's DAVINCH http://www.kobelco.co.jp/english 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.

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.



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 associate with disposal of underwater munitions has been the noise levels and the environmental effects that are created when detonations occur underwater. 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 sea floor 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.



A table of existing technologies below provides a matrix of existing technologies, categorized as to depths for operations and various functions such as detection, sampling and disposal.

TABLE 1.1

		Advantages	Disadvantages
Shallow Depth (0 to 9 meters)			
	Wide Area Detection Technologies		
	Towed Array – Sonar	• 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 • Can not 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
	Towed Array Magnetometers	• Minimal cost “Unlimited” power (function of towing platform) • Real-time data acquisition/man 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 maneuverability • Positioning difficult at deeper depths

		Advantages	Disadvantages
Shallow Depth (0 to 9 meters)			
	Wide Area Detection Technologies		
	Towed Array Dual System Sonar/Magnetometer	• Minimal cost "Unlimited" power (function of towing platform) • Real-time data acquisition/man 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
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV's	• Cost

		Advantages	Disadvantages
Shallow Depth (0 to 9 meters)			
	Localized Detection Technologies		
	SCUBA Divers	• Human evaluation	• Depth restriction (30.48 meters) • Limited search time • Diver safety issues • Restriction to what can be seen or felt • Increased exposure risks
	Surface Supplied Divers	• Human evaluation • Second person verification via camera • Immediate excavation of contacts	• Depth restriction 57.9 meters
	Hand Held SONAR	• Easy to obtain • East to employ • Minimal cost • Enhances diver search capabilities	• Can not detect ferrous materials
	Hand Held Magnetometer	• Easy to obtain • East to employ • Minimal cost • Enhances diver search capabilities	
	Remote Cameras	• Enhances human evaluation • Minimizes human exposure • Highest resolution	• Hard to focus and view underwater anomalies

		• Best method for identification of exposed items	

		Advantages	Disadvantages
Shallow Depth (0 to 9 meters)			
	Environmental Sampling/Characterization Technologies		
	SCUBA Divers	• Human evaluation • Accurate samplings	• Depth restriction (30 meters) • Limited search time • Diver safety issues • Restriction to what can be seen or felt • Increased exposure risks
	Surface Supplied Divers	• Human evaluation • Second person verification via camera • Immediate excavation of contacts	• Depth restriction 57.9 meters
	Surface/Subsurface Collection from Boats	• Easy to obtain • Minimal cost • Enhances human evaluation • Minimizes human exposure	• Less accurate sampling
	Response Action Technologies		

	Floatation Bags	• Accurate retrieval	• Increased risk to divers
	Dredging	• Large volume removal	• Increased risk of detonation • Destruction of coral or endangered species • Inability to recover individual items of ordnance

		Advantages	Disadvantages
Shallow Depth (0 to 9 meters)			
	Response Action Technologies		
	Mechanical Manipulator Arms	• Accurate retrieval • Remote operation • Minimum risk to operators/diver	• Requires frequent repositioning • Requires additional technologies to move munitions to a disposal site
	Blow-in-Place (Detonation)	• Quick and easy to perform	• Potential damage to local environment • Harmful to aquatic life • Increased risk to divers
	Detonation Chamber	• Minimal/no risk to environmental exposure to toxic by-products • Total destruction of toxic filler material by detonation or thermal treatment	• Requires additional technologies to reposition munitions • Requires positioning of a barge to support the weight and size of the Detonation Chamber

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Wide Area Detection Technologies		
	Towed Array – Sonar	• 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 • Can not 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
	Towed Array Magnetometers	• Minimal cost “Unlimited” power (function of towing platform) • Real-time data acquisition/man 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 maneuverability • Positioning difficult at deeper depths

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Wide Area Detection Technologies		
	Towed Array Dual System Sonar/Magnetometer	• Minimal cost “Unlimited” power (function of towing platform) • Real-time data acquisition/man 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
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV’s	• Cost

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Wide Area Detection Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Localized Detection Technologies		
	SCUBA Divers	• Human evaluation	• Depth restriction (100 Feet) • Limited search time • Diver safety issues • Restriction to what can be seen or felt • Increased exposure risks
	Mixed Gas Divers	• 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.)

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Localized Detection Technologies		
	Saturation Divers	• Human evaluation	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth 290 meters
	Atmospheric Divers	• Human evaluation • No decompression requirements for divers	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth 610 meters
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Localized Detection Technologies		
	Hand Held SONAR	• Easy to obtain • East to employ • Minimal cost • Enhances diver search capabilities	• Can not detect ferrous materials
	Hand Held Magnetometer	• Easy to obtain • East to employ • Minimal cost • Enhances diver search capabilities	
	Environmental Sampling/Characterization Technologies		
	SCUBA Divers	• Human evaluation • Accurate samplings	• Depth restriction (30 meters) • Limited search time • Diver safety issues • Restriction to what can be seen or felt • Increased exposure risks
	Surface/Subsurface Collection from Boats	• Easy to obtain • Minimal cost • Enhances human evaluation • Minimizes human exposure	• Less accurate sampling

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Environmental Sampling/Characterization Technologies		
	Mixed Gas Divers	• Divers work independent of support vessel • Human evaluation • Accurate sampling	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth (Nitrogen) (Helium 91 meters)
	Saturation Divers	• Human evaluation • Accurate sampling	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth 290 meters
	Atmospheric Divers	• Human evaluation • No decompression requirements for divers • Accurate sampling	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth 610 meters

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Environmental Sampling/Characterization Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • “Unlimited” power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Response Action Technologies		
	Floatation Bags	• Accurate retrieval	• Increased risk to divers

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Response Action Technologies		
	Dredging	• Large volume removal	• Increased risk of detonation • Destruction of coral or endangered species • Inability to recover individual items of ordnance
	Mechanical Manipulator Arms	• Accurate retrieval • Remote operation • Minimum risk to operators/diver	• Requires frequent repositioning • Requires additional technologies to move munitions to a disposal site
	Blow-in-Place (Detonation)	• Quick and easy to perform	• Potential damage to local environment • Harmful to aquatic life • Increased risk to divers
	Detonation Chamber	• Total destruction of toxic filler material by detonation or thermal treatment	• Requires additional technologies to reposition munitions • Requires positioning of a barge to support the weight and size of the Detonation Chamber

		Advantages	Disadvantages
Medium Depth (9 to 152 meters)			
	Response Action Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement
		Advantages	Disadvantages
Deep Depth (152 to 305 meters)			
	Wide Area Detection Technologies		
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV's	• Cost

		Advantages	Disadvantages
Deep Depth (152 to 305 meters)			
	Wide Area Detection Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Localized Detection Technologies		
	Atmospheric Divers	• Human evaluation • No decompression requirements for divers • Accurate sampling	• Personnel requires specialized training • Requires specialized support equipment • Maximum working depth 610 meters

		Advantages	Disadvantages
Deep Depth (152 to 305 meters)			
	Localized Detection Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV's	• Cost

		Advantages	Disadvantages
Deep Depth(152 to 305 meters)			
	Localized Detection Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Environmental Sampling/Characterization Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement

		Advantages	Disadvantages
Deep Depth (152 to 305 meters)			
	Environmental Sampling/Characterization Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability • Automatic environmental sampling	• Limited hovering capability • Power limited by battery life
	Response Action Technologies		
	Mechanical Manipulator Arms	• Accurate retrieval • Remote operation • Minimum risk to operators/diver	• Requires frequent repositioning • Requires additional technologies to move munitions to a disposal site
	Blow-in-Place (Detonation)	• Quick and easy to perform	• Potential damage to local environment • Harmful to aquatic life • Increased risk to divers

		Advantages	Disadvantages
Deep Depth (152 to 305 meters)			
	Response Action Technologies		
	Detonation Chamber	• Minimal/no risk to environmental exposure to toxic by-products • Total consumption of toxic filler material upon detonation	• Requires additional technologies to reposition munitions • Requires positioning of a barge to support the weight and size of the Detonation Chamber
		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Wide Area Detection Technologies		
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV's	• Cost

		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Wide Area Detection Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Localized Detection Technologies		
	Towed Array Synthetic Aperture Sonar	• Enhance resolution • Increased target identification capability • Low power consumption • 25% greater resolution • 3,000% increase of area coverage • Suited for use in AUV's	• Cost

		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Localized Detection Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life
	Environmental Sampling/Characterization Technologies		
	Autonomous Underwater Vehicle (AUV)	• Speed independent of depth • Depth limited only by vehicle design (deep depths capable) • Better line tracking during surveys • Significant maneuverability	• Limited hovering capability • Power limited by battery life

		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Environmental Sampling/Characterization Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement
		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Response Action Technologies		
	ROV	• Depth limited only by vehicle design (deep depths capable) • Exceptional maneuverability and hovering • "Unlimited" power (function of host platform) • Able to manipulate items/man-in-the-loop	• Very limited horizontal movement

		Advantages	Disadvantages
Extreme Depth (over 305 meters)			
	Response Action Technologies		
	Mechanical Manipulator Arms	• Accurate retrieval • Remote operation • Minimum risk to operators/diver	• Requires frequent repositioning • Requires additional technologies to move munitions to a disposal site
	Blow-in-Place (Detonation)	• Quick and easy to perform	• Potential damage to local environment • Harmful to aquatic life • Increased risk to divers
	Detonation Chamber	• Total destruction of toxic filler material by detonation or thermal treatment	• Requires additional technologies to reposition munitions • Requires positioning of a barge to support the weight and size of the Detonation Chamber

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