Report of Findings

ORDNANCE REEF (HI-06) TECHNOLOGY DEMONSTRATION

FOR THE REMOTELY OPERATED UNDERWATER MUNITIONS RECOVERY SYSTEM (ROUMRS)

and

ENERGETICS HAZARD DEMILITARIZATION SYSTEM (EHDS)

Prepared for:

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Acronyms

3Rs	Recognize, Retreat, Report
ABS	America Bureau of Shipbuilding
APP	Accident Prevention Plan
AR	Army Regulation
ARA	ARA, Inc.
ATSDR	Agency for Toxic Substances and Disease Registry
AWS	American Welding Society
BMP	Best Management Practices
CAMIP	Coral Avoidance and Minimization of Injury Plan
C&C	City and County
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COTS	Commercial Off-the-Shelf
DA	Department of the Army
DoD	Department of Defense
DDESB	Department of Defense Explosives Safety Board
DERP-FUDS	Defense Environmental Restoration Program - Formerly Used Defense Site
DMM	Discarded Military Munitions
DSV	Demilitarization Support Vessel
EHDS	Energetic Hazard Demilitarization System
EM	Engineer Manual
EOD	Explosive Ordnance Disposal
EP	Engineer Pamphlet
EQT	Environmental Quality Technology
ER	Engineer Regulation
ESP	Explosives Safety Site Plan
ESQD	Explosive Safety Quantity Distance
ESO/SSO	Explosive Safety Officer/Site Safety Officer
FB	Force Feedback
FT	Feet/Foot
FSW	Feet Sea Water
GPS	Global Positioning System
HCN	Hydrogen Cyanide
HDTV	High Definition Television
HE	High Explosive
HI-06	Sea Disposal Site Hawaii 06
HPU	Hydraulic Pumping Unit
Hr	Clock Hours
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
lb	Pound

LED……………………………. Light-emitting Diode
MC………………………….. Munitions Constituents
MDAS……………………… Material Documented as Safe
MDEH……………………… Material Documented as Hazardous
MEC………………………… Munitions and Explosives of Concern
MGFD……………………… Munitions with the Greatest Fragmentation Distance
MPPEH…………………… Material Potentially Presenting an Explosive Hazard
MSD………………………… Minimum Separation Distance
Mhr………………………… Man Hours
NC…………………………… Nitrocellulose
NEW……………………… Net Explosive Weight
NFB………………………… Non-force Feedback
nm…………………………… Nautical Mile
NMFS……………………… National Marine Fisheries Service
NO………………………….. Nitrogen Oxide
NO_2………………………… Nitrogen Dioxide
NTSC………………………. National Television System Committee
NOAA……………………… National Oceanic and Atmospheric Administration
NOSSA……………………. Naval Ordnance Safety and Security Activity
NVESD……………………. Night Vision and Electronic Sensors Directorate
ODASA-ESOH…………. Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health
ODC………………………… Other Direct Cost
OII……………………………. Oceaneering International, Inc.
ORCC………………………. Ordnance Reef Coordinating Council
PACD………………………. Portable Acoustic Contraband Detector
POD………………………… Pacific Ocean Division
POH………………………… Honolulu District
RCBO………………………. Radiant Convective Batch Ovens
RDECOM………………… Research, Development and Engineering Command
RDX………………………… Cyclotrimethylenetrinitramine
ROV………………………… Remotely Operated Vehicle
ROUMRS………………… Remotely Operated Underwater Munitions Recovery System
RSV…………………………. ROV Support Vessel
SAA………………………… Small Arms Ammunition
SCR…………………………. Silicon Controlled Rectifiers
SONAR……………………. Sound Navigation and Ranging
SPAWAR………………….. Space and Naval Warfare Systems Command
SSHP………………………. Site Safety and Health Plan
TNT…………………………. Trinitrotoluene
UH………………………….. University of Hawaii
US…………………………… United States
USACE…………………… US Army Corps of Engineers
USACHPPM……………. US Army Center for Health Promotion and Preventive Medicine
USAPHC………………….. US Army Public Health Command

USATCES…………………. US Army Technical Center for Explosive Safety
USBL……………………….. Ultra Short Base Line
USCG………………………. US Coast Guard
USDOT…………………….. US Department of Transportation
UWMM………….......... Underwater Military Munitions
UXO………………………… Unexploded Ordnance
UXOCOE…………………. UXO Center of Excellence
WWTP……………………. Wastewater Treatment Plant

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1. INTRODUCTION

The United States (US) Department of the Army (Army) under its Environmental Quality Technology (EQT) Program conducted a Technology Demonstration (Demonstration) at Department of Defense (DoD) Sea-Disposal Site Hawaii 06 (HI-06), which is a near-shore munitions site in waters off Waianae, Oahu, Hawaii (see Plate A-1, Appendix A). HI-06 is locally referred to as "Ordnance Reef." The Army conducted this demonstration over a 25-day period beginning on 11 July 2011. This Demonstration involved the limited recovery of underwater military munitions (UWMM) and the destruction (destruction) of any recovered UWMM using commercially available technologies that have been adapted, including development of new components and procedures, for the recovery and destruction of UWMM.

This Demonstration provides DoD with technologies required to address UWMM at other locations where such munitions are determined to pose an unacceptable risk to human health and the environment. In addition, this Demonstration addressed some of the concerns raised by the state of Hawaii and local communities about the UWMM present at Ordnance Reef (HI-06). This Demonstration assessed the Remotely Operated Underwater Munitions Recovery System (ROUMRS) and Energetic Hazard Demilitarization System (EHDS).

Although ROUMRS is required to be able to set a charge on an UWMM for detonating in place a munition for which the risk of movement is considered unacceptable, the demonstration did not include an open detonation of UWMM either in place (underwater) or during the destruction and demilitarization of recovered UWMM.

The following organizations were involved in the Demonstration:

- Office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health (ODASA-ESOH)
- US Army Corps of Engineers' (USACE) Pacific Ocean Division (POD) and Honolulu District (POH)
- National Oceanic and Atmospheric Administration (NOAA)
- ARA Incorporated (ARA)
- Oceaneering International, Inc. (OII)
- Space and Naval Warfare Systems Command (SPAWAR)
- U.S. Army Night Vision Laboratory
- University of Hawaii (UH)

This Report of Findings was written to meet the following criteria:

- Provide a summary of the system performance, including a descriptions of processing methods
- List munitions and other material processed and disposed of during the Demonstration

- Provide documentation for and related to the disposal and destruction of munitions and other material, including recycling
- Present photographs and maps
- List the operating costs for Demonstration-related expenses that could be incurred should the technology be used at other locations where UWMM are present
- List the lessons learned during the Demonstration.

1.1. Historical Background for Ordnance Reef (HI-06)

During a benthic survey of the Waianae Wastewater Treatment Plant (WWTP) sewage outfall in 1992, the City and County (C&C) of Honolulu, Department of Wastewater Management's oceanographic team discovered military munitions between 0.3 and 0.6 miles northwest of the existing sewage outfall's diffuser at depths of 30 to 120 feet. The UWMM observed were suspected to include clipped .50 caliber small arms ammunition (SAA) and projectiles (possibly 3- to 5-inch naval projectiles) of various types, some between 1 and 3 feet in length. The C&C's oceanographic team also discovered UWMM south of the sewage outfall and just west of a Hawaii-designated fish haven (NOAA, 2007).

In 2002, USACE conducted a study of Ordnance Reef (HI-06) to determine its eligibility for inclusion in the Defense Environmental Restoration Program-Formerly Used Defense Sites (DERP-FUDS). At USACE's request, the US Navy's Explosive Ordnance Disposal (EOD) Detachment provided diving and underwater survey support to USACE's study. The Navy EOD Detachment surveyed Ordnance Reef (HI-06) and identified roughly 2,000 UWMM, which it categorized as most likely discarded military munitions (DMM). However, Ordnance Reef (HI-06) was determined ineligible for a response under the DERP-FUDS Program because DoD never owned, leased, otherwise possessed the site, nor did it ever exercise control over it, except to use the area for the disposal of military munitions.

In May 2006, the Army and Navy funded NOAA to conduct a screening-level survey of Ordnance Reef (HI-06). The NOAA survey, which was limited to depths of approximately 300 feet, determined the boundaries of Ordnance Reef (HI-06), determined the location of the UWMM present, provided information for use in identifying the types and approximate quantities of UWMM detected, and analyzed sediment and fish tissue samples for munitions constituents (MC) (i.e., metals and explosives) (NOAA, 2007). NOAA released its independent report in March 2007. NOAA determined that the UWMM present extended from depths of 24 feet to over 300 feet, the maximum depth of the study. Many of the UWMM observed were heavily fouled with algae and benthic organisms. In some cases, UWMM were observed with substantial coral growth.

NOAA's Survey Report provided the Army and DoD screening-level data allowing the Army to assess the potential explosives safety and human health or environmental risks associated with the UWMM present and determine whether a response was required at Ordnance Reef (HI-06).

The US Army Technical Center for Explosives Safety (USATCES) and the US Navy's Naval Ordnance Safety and Security Activity (NOSSA) are responsible for overseeing their respective Service's explosives safety programs. These agencies independently concluded that the UWMM present did not pose an immediate explosives safety risk to public, and only deliberate activities (e.g., divers disturbing UWMM) posed a threat to those who use Ordnance Reef (HI-06) for recreational-related and other activities. The DoD Explosive Safety Board (DDESB), which oversees the Service's explosives safety programs and independently reviewed NOAA's report, endorsed this conclusion. Subsequently, the Army, as part of its 3Rs (**Recognize**–when you have encountered a munition and that munitions are dangerous, **Retreat**–do not touch, move or disturb it, **Report**–immediately notify local law enforcement (i.e., call 911) of what you saw and where) Explosives Safety Education Program implemented a comprehensive public education effort that focused on, but was not limited to, the communities near Ordnance Reef (HI-06).

The Army's Center for Health Promotion and Preventive Medicine (USACHPPM), now the Army's Public Health Command (USAPHC), is responsible for health and environmental risk assessments for the Army. USACHPPM concluded that (a) the contaminant levels from any MC detected were all well below risk-based levels; and (b) the only metals detected in fish tissue did not appear to be associated with MC from the UWMM present at Ordnance Reef (HI-06). Based on available data, the risk assessors concluded that it was unlikely that the UWMM pose an unacceptable human health risk. The ecological evaluation found no overt signs of stress or ecological impact. However, both agencies, along with the US Department of Health and Human Services' Agency for Toxic Substances and Disease Registry (ATSDR), which reviewed NOAA's report, concluded that there were data gaps that needed to be addressed to answer the community's questions regarding possible risk to human health and/or the potential contamination of ocean food resources. Site activities to date have included:

- 1980 – Researchers conducting a current survey for Waianae WWTP effluent outfall extension discover .50-caliber bullets in area
- 1992 – Munitions discovered during a survey conducted for extension of Waianae WWTP ocean outfall
- 1996 – USACE completes an Inventory Project Report for Offshore Waianae Sewage Outfall (H09HI047500)
- 2002 – EOD Detachment, Pearl Harbor, Hawaii conducts a diver survey of the area to identify munitions and map their extent
- 2002 – USACE POD completes a study Offshore Waianae Sewage Outfall (H09HI047500) to determine eligibility for DERP-FUDS
- 2006 – NOAA conducts a survey of the site consisting of mapping the extent of munitions; and the sampling and analysis of fish and sediment for explosives and metal levels
- 2007 – ODASA-ESOH establishes the Ordnance Reef Coordinating Council (ORCC)
- 2007 –USATCES produces a report evaluating explosives safety risks at site

- 2007 – USACHPPM reviews NOAA report and concludes that chemicals detected do not present a public health hazard to adults and children who may consume subsistence amounts of these species
- 2007 –ATSDR completes a public health consultation, which finds little probability of health impacts, but concludes additional data is needed to fully evaluate the public health implications
- 2007 – Army distributes 22,000 coloring books through the public school system in Hawaii to increase public awareness of dangers of unexploded ordnance (UXO)
- 2007 – USACE POD issues a contract to UH to address the data gaps from the 2006 screening level survey. The work is to include human health and screening ecological risk assessments
- 2009 – UH completes sampling
- 2010 – NOAA survey of coral in the Ordnance Reef (HI-06) area
- 2011 – NOAA produces the Coral Avoidance and Minimization of Injury Plan (CAMIP) to guide the Ordnance Reef (HI-06) demonstration effort
- 2011 – Draft Environmental Assessment and finding of no significant impact for the Demonstration are put out for public comment
- 2011 – No significant comments received and finding of no significant impact for the Demonstration signed by Army
- 2011 – Army conducted its Ordnance Reef (HI-06) Technology Demonstration

1.2. Site Location and Conditions

Ordnance Reef (HI-06) is in near-shore US coastal waters along the western, leeward side of the Island of Oahu, Hawaii. The nearest towns are Waianae approximately three miles to the northeast, and Maili approximately five miles to the east (NOAA, 2007). The Demonstration site encompasses a surface area of approximately 1,695 acres and ranges in depth from 20 feet to approximately 120 feet of water. The northern portion of Ordnance Reef (HI-06) extends into Pokai Bay to the northeast and just beyond the Waianae WWTP sewer outfall to the south. The depth at the work area was 20 to 120 feet of water.

Understanding the environmental conditions at Ordnance Reef (HI-06) was important in determining the equipment (e.g., selection of lights, cameras, SONAR) and techniques to be used in collecting data. It was also important to understanding how the environment would affect the condition of UWMM.

Due to the impact of the rain shadow on storms driven by the trade winds, Waianae is usually one of the driest areas on Oahu. The average annual rainfall in Waianae is 21.3 inches (55 centimeters), less than half of the average for Oahu as a whole. Indeed, although there were light rains during the Demonstration, rain storms did not occur during the field activities. On the leeward side of the Waianae Mountains, winds in the work area were relatively light, and the effect on the sea states was minimal. The sea state never reached level 3, which was the maximum level at which field activities could occur.

Because the Army scheduled this Demonstration for the summer, which is the dry season, field activities were less likely to be impacted by high waves, storms, turbidity, and high winds. Additionally, because whales are not commonly present in Hawaii during July and August, field activities were less likely to be impacted by the presence of marine mammals.

1.3. NOAA Support

A key feature of the Demonstration was the Army's interagency agreement with NOAA for assistance in developing plans and best management practices (BMP) to avoid injuries to coral of significant ecological value and minimize impacts to benthic habitat as a whole. NOAA acts on behalf of the U.S. Department of Commerce as a natural resource trustee with the responsibility for protecting and restoring aquatic resources and their associated habitats. The Army requested NOAA's support to ensure that BMP for protection of coral and other benthic habitats became an integral part of this Demonstration.

In 2010, NOAA began collaborating with the Army to assess the corals present within Ordnance Reef (HI-06). Working together, and with both its prime contractor (ARA) and the State of Hawaii, these organizations analyzed the field activities that would occur and developed procedures to avoid intentional and minimize any inadvertent impacts to coral and other benthic habitats. Of particular concern were remotely operated vehicle (ROV) activities (e.g., dragging the tether, positioning the ROV for recovery, recovery of munitions) and mooring activities for both the ROV support vessel (RSV) and demilitarization support vessel (DSV).

The coral avoidance and minimization of injury efforts occurred in three phases. These include:

- Phase I: Pre-Demonstration survey of corals and munitions, and assistance with development and review of BMP;
- Phase II: Post-recovery survey to assess impacts to coral, loss of corals from munitions recovery, and recommend mitigation strategies for those impacts; and
- Phase III: Completion of required coral mitigation activities by the Army.

1.3.1. Phase I

Phase I included surveying the areas where UWMM were to be recovered and providing the Army and contractors information on the relative risk of working or mooring in the various areas. NOAA conducted 78 survey dives for Phase I, taking 1,862 photographs of munitions and habitat types. The area covered during these dives was approximately 72 acres. Within areas designated for ROV operations, NOAA surveyed approximately 52 acres. It also photographed and calculated approximate geographic coordinates for roughly 21,200 UWMM.

Phase I findings and recommendations were included in NOAA's CAMIP report, released in March 2011. NOAA coordinated development of the CAMIP with the Army; federal, state, and local resource agencies; and stakeholders. The CAMIP addresses the relative risk of coral injury in the three work areas based on relief of the area, abundance of coral present, and the presence of corals of high ecological value.

Phase I efforts allowed the Army to plan its field activities to anticipate and avoid or minimize possible Demonstration-related coral injuries. NOAA's assistance allowed the Army to guide placement of moorings and anchorages, direct recovery efforts, and develop and use BMP throughout the Demonstration. To reduce potential coral injuries during the Demonstration, the Army prioritized the recovery of UWMM in areas of uncolonized hard bottom and sand while exercising caution in areas of higher coral cover. The CAMIP also included possible emergency restoration efforts to reattach corals that might become dislodged during recovery activities (NOAA 2011).

NOAA personnel were onsite during the Demonstration and available for consultation during mooring operations for the RSV and the DSV as well as placement of the salvage baskets and ROV operations. NOAA personnel were available to support ARA in selecting work areas. This support included actively providing ARA with coordinates for selecting mooring locations and the placement of salvage baskets on the sea floor.

Consulting with NOAA allowed ARA to select areas with lower coral concentrations for its ROV and UWMM recovery operations. To facilitate NOAA's efforts and coordination, ARA provided NOAA software to view video and photographs of ROV operations on a daily basis. This allowed NOAA to evaluate the impact of the ROV operations on the coral.

When determining whether to recover a particular UWMM, a number of factors were considered. Important among these was whether there was sufficient room to allow the ROV to maneuver around a targeted UWMM without damaging coral or other benthic habitats. When coral growth of 12 inches or greater was observed on a munition targeted for recovery, or a munition was in a location where nearby coral could be damaged during recovery, the decision was to leave the munition in place. NOAA personnel were often also on the RSV to evaluate the environment surrounding the UWMM being recovered. This helped ARA personnel develop the criteria on whether or not a particular UWMM would be recovered.

1.3.2. Phase II

During Phase II, NOAA conducted a post-Demonstration survey to assess any inadvertent injuries that occurred to coral or other benthic habitats. To date, NOAA has determined that such injuries were minimal. NOAA will recommend coral mitigation measures, which it will scale to the type and level of injuries that occurred, for the Army's consideration as a means of compensating for those inadvertent injuries.

1.3.2. Phase III.

During Phase III, the Army will work with NOAA, the State of Hawaii and stakeholders to determine the mitigation measures that it will implement.

1.4. Objectives of the Ordnance Reef (HI-06) Demonstration

This Demonstration was designed and conducted in a manner protective of human health and the environment. Collectively, ROUMRS, EHDS and related operations demonstrated technologies for the recovery of UWMM, and procedures for the evaluation of material potentially presenting an explosive hazard (MPPEH), and the destruction of material documented as an explosive hazard (MDEH) at-sea. The potential risks posed to the public as well as personnel involved in the Demonstration were limited processing (e.g., identifying, evaluation the explosive hazard, destruction) of all recovered munitions and MDEH on the off-shore DSV. Disposal operations concluded as soon as all recovered munitions were destroyed.

Figure 1-1, 1-2, and 1-3 show the concept of operations for ROUMRS and the EHDS. Overall, the Army's Demonstration validated both ROUMRS capabilities to locate, identify and recover UWMM and EHDS capabilities to destroy and demilitarize recovered munitions at sea, while minimizing impacts to human health and the environment. The following summarize the overall objectives of the Army's Demonstration:

- ROUMRS Objectives:
  - Design, assemble, integrate and demonstrate a system for the safe remote recovery of munitions with minimal environmental impact.
  - Develop adaptable attachments and lifting mechanisms that would allow topside operators to provide a tentative identification of UWMM being recovered, including their armed state; characterize and recover or detonate UWMM at depths ranging from 20 to 300 feet. (Note: Although ROUMRS was designed for these water depths and is readily adaptable to greater depths, the basic system components are rated to 6,000 feet.) ARA was required to demonstrate that the system was:
    - ✓ Capable of manipulating or grabbing a variety of UWMM (e.g., SAA, medium and large caliber projectiles, rockets and missiles, and bombs) recovering the munitions from the ocean floor with minimal environmental damage, and moving recovered munitions safely underwater to another underwater location and to the surface for destruction
    - ✓ Capable of placing a charge on UWMM when in-place detonation is required for safety reasons - no planned or accidental detonations occurred during this Demonstration
    - ✓ Engineered to contain MC (e.g., propellants, explosive fillers, metals) and metal debris to minimize release of such constituents from deteriorated (e.g., corroded) munitions during the recovery process

    - ✓ Equipped with sufficient methods (e.g., cameras, laser based measurement system) to allow an operator to identify UWMM by family (e.g., 155 mm, 100 pound (lb) bomb), most likely type (e.g., high explosive (HE)), and category (i.e., UXO, DMM) without contacting the munitions

- EHDS Objectives:
  - Design and demonstrate a system that can be operated at sea to safely destroy and demilitarize recovered munitions, removing the explosive hazard
  - Destroy MDEH in a manner that allows such material to be documented as safe (MDAS) and released for recycling
  - Process munitions including receiving and lifting recovered munitions and other material recovered by ROUMRS to the DSV for processing
  - Alleviate public concerns by remotely opening recovered munitions and thermally decomposing energetic compounds (the explosive fill) without open burning, open detonation, or incineration
  - Comply with applicable explosives safety requirements (e.g., Army and DDESB) and with state and federal regulations
  - Test the system's operation including
    - ✓ Use of specialized destruction equipment and processes to remotely open munitions and other material containing energetic compounds, and
    - ✓ Disposal of exposed explosive MC using radiant convective batch ovens (RCBO) - a thermal treatment process using radiant and convective heat
  - Demonstrate the RCBO's ability to decompose explosive MC using heat while providing temperature control, and minimizing energy use (Note: Use of RCBO is not considered incineration, as at no time do flames or radiant heat elements contact energetic compounds. Thermal decomposition of explosives is an irreversible reaction that breaks the chemical bonds of the compounds and does not generate explosive gases.)
  - Demonstrate that after heating and demilitarization of the explosive hazards, the explosive safety status of all metal scrap can documented as MDAS and subsequently recycled
- Other Objectives:
  - Perform all demilitarization activities per a DDESB-approved, site-specific ESP
  - Develop operating procedures for ROUMRS and EHDS
  - Develop work plans, required explosive safety submissions (RESS), and other plans and documentation required for the Demonstration
  - Mobilize and demobilize ROUMRS and EHDS, supporting tools, and personnel to and from Ordnance Reef (HI-06)
  - Report on the effort, cost and performance, and lessons learned, including a listing of all munitions recovered during the Demonstration's field activities

Figure 1-1 ROUMRS CONOPS

Remotely Operated Underwater Munitions Recovery System Facts

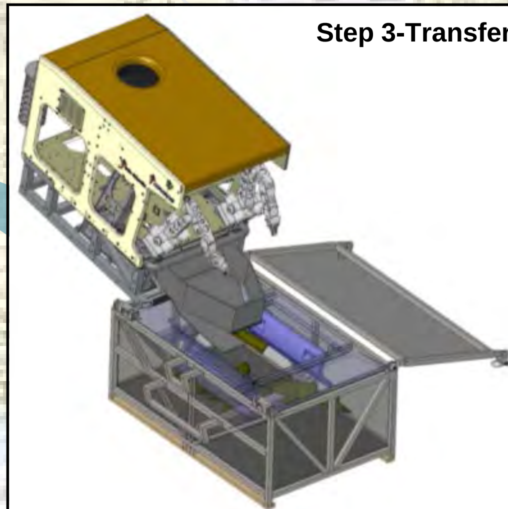
Step 1-Spot Basket

- Landing site inspected for coral/live rock
- Salvage Basket lowered to bottom and released
- ROV positions Basket near concentrated UWMM, un-pins and opens upper door

Step 2-Loading

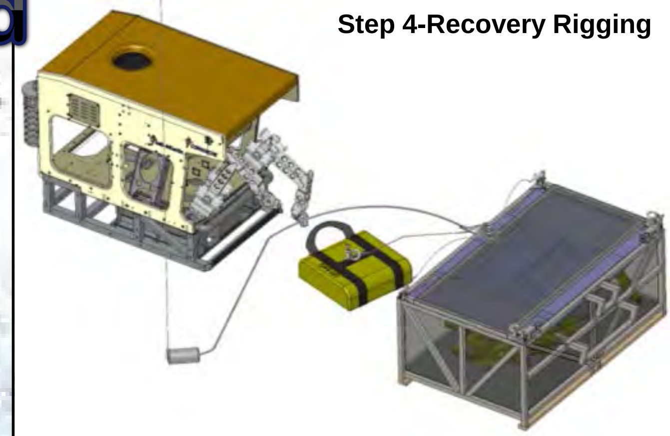
- Hopper is extended out of Recovery Skid
- UXO is documented (video, laser scaling)
- Manipulators/tooling used to pickup UWMM
- Small debris vacuumed into Canister Filters
- Retract Hopper

Step 3-Transfer



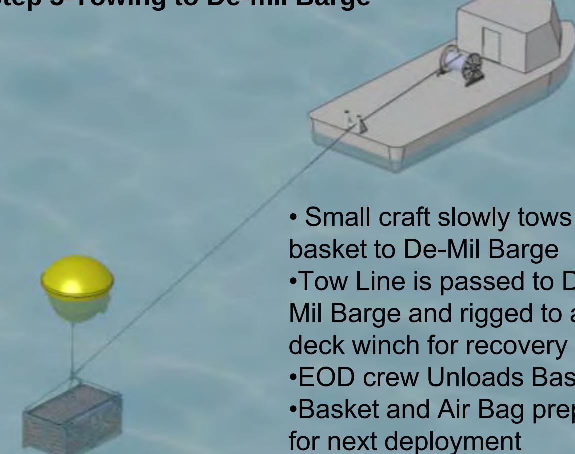
- ROV transits to and lands on Salvage Basket
- Hopper extended, contents transferred, and Hopper retracted
- Canister Filters jettisoned and recovered
- ROV transits to next Recovery Site

Step 4-Recovery Rigging



- Air Lift Valise is lowered, ROV moves it to Basket
- Air Lift rigging and Tow/Recovery Line connected
- ROV turns ON air valve and inflates Lift Bag
- Salvage Basket ascends to surface

Step 5-Towing to De-mil Barge



- Small craft slowly tows basket to De-Mil Barge
- Tow Line is passed to De-Mil Barge and rigged to a deck winch for recovery
- EOD crew Unloads Basket
- Basket and Air Bag prepped for next deployment

Figure 1-2 ROUMRS CONOPS

ROUMRS Facts

Optics
- (2) Wide Angle Color-1 fixed , 1 on tilt actuator
- (1) 36X Color Zoom on Pan/Tilt actuator
- (1) Manipulator Color Camera w/ LED light
- (2) Lasers with line beam optics

Manipulators
- Dual 7-function arms, (1) w/ force-feed back

Hydraulics
- 15kW HPU with 16 function valve pack

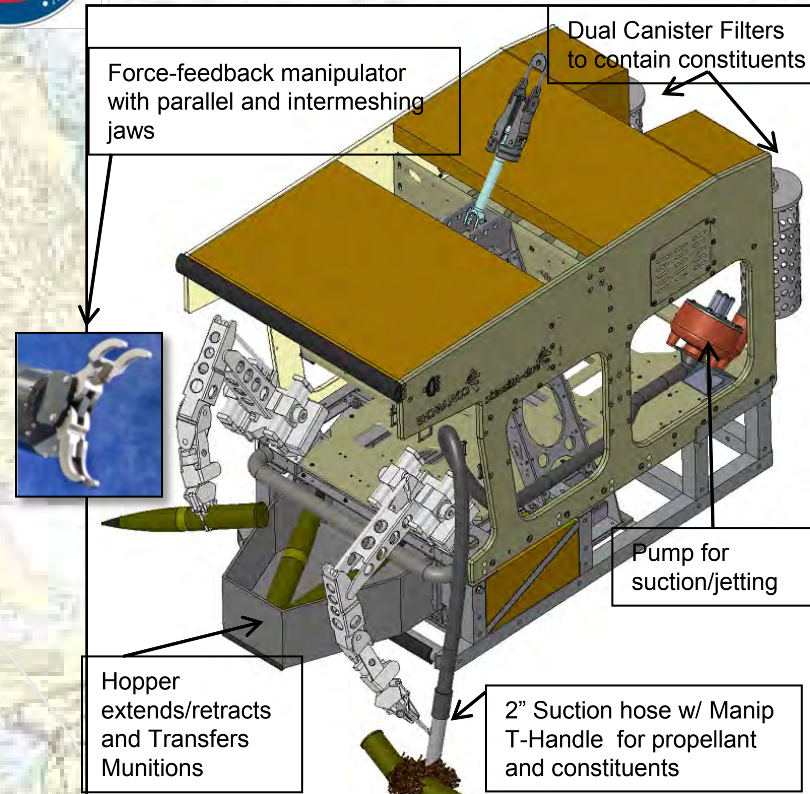
Vehicle rated for 300m operations
- Upgradable to 2000m – requires floatation change

Thrusters
- (3) vertical 496LB up/down thrust
- (4) horizontal 496 LB fwd/rev/lateral thrust

Hopper Assembly
- 200LB lift capacity with a 5.8 FT3 fill volume

Suction/jetting pump with Canister Filter
- 3/16" filter-passes sand/retains propellant grains
- Suction nozzle carried by manipulator
- Canister Filters are jettisoned and later recovered in Salvage Basket

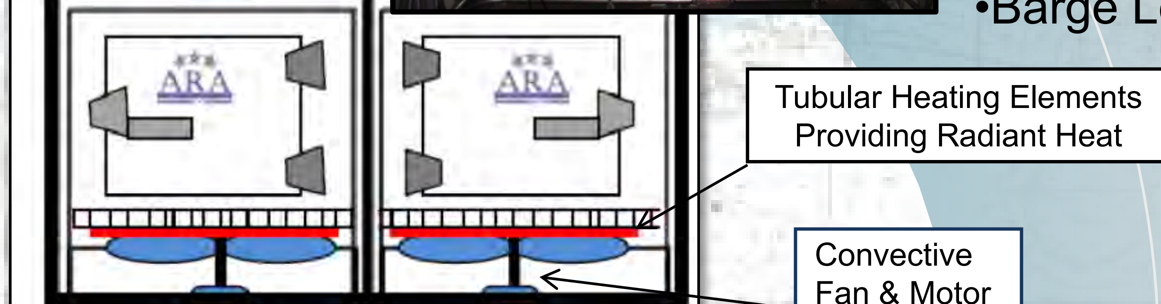
Onboard Sensors
- Scanning Sonar, depth, heading, roll/pitch

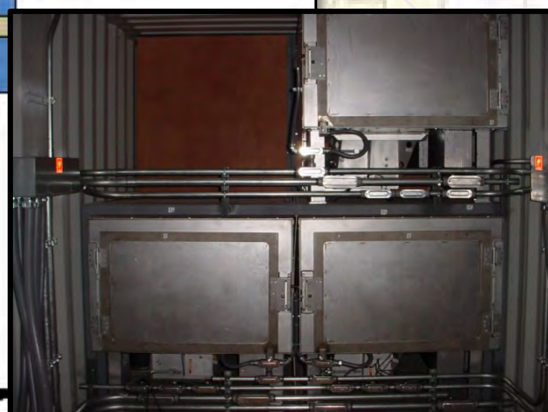


ROV w/ Skid (nominal)
DIMS: 90"L x 51"W x 69"H
Air Weight: 3040 LBS
Seawater Weight: +200LBS

Figure 1-3 EHDS CONOPS

Energetic Hazard Demilitarization System Facts





- Most suitable technology for application at Ordnance Reef
- Munitions Remotely Cut Open
- Energetic Compounds Treated in 6 Radiant/Convective Batch Ovens
- Temperatures controlled and monitored remotely on touch screen monitor
- Through rate of ≈500/lbs NEW /day
- Ideally suited for environmentally sensitive locations
- Not Incineration – low temperature with no open flame.
- Recycle metals locally
- Barge Located System

2. TECHNOLOGY DESCRIPTION

The Army conducted two technological systems (ROUMRS and EHDS) demonstrations at Ordnance Reef (HI-06) concurrently. This section describes these technologies while the Demonstration's field activities are described in Section 4.

ROUMRS was designed for the recovery of UWMM at a site where the potential risk posed by the presence of UWMM is determined to require a removal action. EHDS was designed to treat (destroy) recovered munitions and any MPPEH evaluated and determined to be MDEH.

The Army's Demonstration assessed whether ROUMRS could safely recover UWMM, and EHDS could safely destroy any recovered munitions in an environmentally benign manner. The EHDS design and operations decrease the potential explosives safety hazards (e.g., requiring transport of munitions through populated areas to a designated disposal site) posed to the public or response workers. The systems also minimize potential impacts to the environment by reducing a need for blow-in-place operations.

- ROUMRS uses a standard underwater ROV fitted with components to remotely locate and recover UWMM.
- EHDS is a combination of proven munitions destruction technologies, which are used on land, and were assembled and placed on a barge to provide for the safe destruction of recovered UWMM at sea.

Both systems are capable of being deployed offshore. ROUMRS was deployed on a landing craft type barge. This work vessel, the *Huki Pau*, is a 74-foot twin-screw workboat that was set up to support the ROV operations and designated the RSV. The *Huki Pau*, which was a vessel of opportunity, is berthed in Oahu's Honolulu harbor. This vessel has a wide open deck that was appropriate for tending the ROV tether. It is equipped with a knuckle-boom crane that was appropriate for deploying the ROV. As a rule of thumb, ROUMRS can be operated from a vessel that is roughly 55 to 74 feet in length. The electronics for ROUMRS and the electrical power to drive the ROV thrusters and power other ROUMRS systems was supplied by a rented 20 kVA generator mounted on the rear of the *Huki Pau*.

The EHDS was deployed on a barge designated the DSV. The DSV was anchored within the operational area. The barge selected as the DSV was chosen based upon the explosives safety separation distances required to provide for the safety of operators on the DSV and to reduce the potential for propagation should an inadvertent detonation occur. The barge, which was a compartmentalized steel structure with a deck composed of rail road tie size timbers, had dimensions of 135 x 50 x 11 foot. Ancillary equipment required to support the EHDS on the DSV included a second 150 kVA generator and diesel supply, a four point mooring system, and a ready fresh water supply.

2.1. ROUMRS

ARA and OII designed, integrated and assembled ROUMRS' components to address the Army design criteria (Table 2-1). ROUMRS consists of commercial off-the-shelf (COTS) components integrated into a system specifically designed to meet the Army's criteria for recovery of UWMM.

Table 2-1: Army UWMM Recovery System Basic Design Criteria

Design criteria	Design parameters
Recovery vehicle/equipment operations	
Operating temperatures	- 2 to 32 degrees Celsius (saltwater) - 20 to 43 degrees Celsius (air)
Depth capability	6 to 91 meters water, adaptable to 305 meters
Current speed at depth	Capable of working in up to 2 knots, 1.5 knots when equipped with basket/skid for sample or munitions collection
Launch/recovery operations	Sea state 3
Transport logistics	6 meter International Organization for Standardization (ISO) containers or smaller
Operating vessel requirements	Common commercial 17 to 23 meter vessel of opportunity or smaller
Surface launch and recovery equipment	Generic to vessel of opportunity, A-frame or crane rated for 2.5 tons at 3 meters from vessel
Lifting capability of manipulators	At least 68 kilogram projectile shape (155 mm projectile)
Navigation	± 2.5 meters topside ± 5 meters underwater
Recovery capabilities	SAA, loose propellant, munitions having lost structural integrity. Must be able to contain bulk energetic materials.
Munitions assessment	Capable of supplying sufficient data real-time to allow UXO-qualified personnel to tentatively identify the munition by family (e.g., 155 mm, 100 lb bomb), type (e.g., HE) and category (i.e., as UXO, DMM)
SONAR	High resolution scanning for bottom navigation and target location
Photo/video equipment	Low light camera for navigation, high resolution camera for work area documentation, camera on manipulator, auxiliary camera, digital stills from a dedicated camera or high resolution video frame grabber
Recording	Video, SONAR, digital stills must be recorded on digital media and stamped with date/time and geo-referenced position
Measuring	Laser scaling system to aid in identification of munitions in situ
Recovery vehicle/equipment operations	
Provisions for optional capabilities	Ability to accommodate magnetometers, gradiometer, side scan SONAR, cameras, sediment/water sampling tools, in situ chemical sensor
Overburden removal	Light sand, silt, mud removal using suction or blowing from pump, scoops to be used by manipulators as necessary, brushes to clear items surface for identification of markings
Crew size	Maximum of 4 per 12 hour shift, or 7 for 24 hour operations (does not include personnel for vessel operations)
Endurance	Capable of working a minimum of 160 continuous hours in the

Design criteria	Design parameters
	water between recoveries
Munitions recovery by vehicle or lift package	
Vehicle lift capability	Minimum of 59 kilograms dynamic lift using onboard thrusters
Lifting basket/bag capability	Capable of lifting 910 kilograms from a depth of 60 meters
Lifting of large munitions	Capable of lifting a 910 kilogram bomb shape using basket or lift bags
Containment	Lift basket/bag must be provisioned to allow containment of propellant grains, bulk explosives and munitions debris while allowing fine sand and water to pass through
Distance from munitions to detonation or transfer to alternate transport	Lift basket shall be designed to be towed up to one km at sea state 3 or less by small craft and sturdy enough to be lifted from the water by a crane or dragged onto beach

ROUMRS consists of several major subsystems. These subsystems include the primary platform - the ROV, manipulators, sensors and navigation systems, ROV recovery equipment and the salvage baskets. Subsequently each subsystem is made up of the several components.

2.1.1. Remotely Operated Vehicle (ROV)

The final ROV configuration had a low relative magnetic signature. This was determined to be necessary for future installation of various sensors that could be affected by vehicles with higher relative magnetic signatures. As a result, including hydraulically propelled vehicles was ruled out, because of their greater iron mass and higher relative magnetic signatures. Only electrically propelled vehicles were considered. The basic design criteria are presented in Table 2-1. The equipment selected for the device meet or exceeds that design criteria. The final configuration of the base ROV includes:

- Frame
- Flotation
- Thrusters
- Onboard hydraulics
- Vehicle and topside controls
- Topside power distribution
- Umbilical
- Launch and recovery support equipment.

The ROV is equipped with tools to support recovery of the UWMM collected by the ROUMRS manipulators. The ROV recovery equipment includes:

- Recovery hopper with integral basket, actuator and control interface
- Suction pump and filtration system.

An industry search for ROV candidates that met or exceeded the basic design criteria, as presented in Table 2-1, was completed. Of these candidates, the final selection of the ROV was based on:

- Recovery equipment interfacing (ability to readily interface the recovery skid, manipulators, manipulator tooling, suction pump)
- Quality (number of fielded systems)
- Delivery time (not including shipping)
- Costs (not including shipping).

Those ROV units considered included:

- Sub Atlantic Comanche
- Saab Sea Eye Panther XT Plus
- Saab Sea Eye Jaguar.

In comparison with the other base ROV candidates, Sub Atlantic Comanche exhibited superior qualities in cost, recovery equipment interfacing, delivery, and vertical thrust (needed to lift loads in excess of 200lbs).

2.1.2. Manipulators

The manipulators are mounted on the base ROV and are used to handle any items that are acquired by ROUMRS. The manipulators include:

- Port and starboard manipulators
- Control valves
- Topside controls.

An industry search for manipulator candidates that met or exceeded the design criteria was completed. Of these candidates, the final selection was based on:

- Operator interface
- Quality (control precision)
- Installation and interface to base vehicle
- Delivery time (not including shipping)
- Costs (not including shipping).

Manipulators considered include:

- Kraft GRIPS 7-function force feedback (FB)
- Kraft GRIPS non-force feedback (NFB)
- Shilling ORION 7-function proportional (7P)
- Shilling ORION 7-function rate (7R)
- Hydro-Lek HLK-HD6R: 6-function rate controlled.

In comparison with the other manipulator candidates, Kraft GRIPS were superior in quality and cost. Kraft GRIPS manipulators have a unique FB feature that permits operators to “feel” resistance when gripping or pushing on an object. These manipulators also use a unique operator interface that is highly intuitive and significantly reduces the time for the operator to become proficient. Both qualities are extremely important for the safe handling of munitions.

2.1.3. Sensors and Navigation Systems

The sensor and navigation systems include:

- Lights
- Scaling lasers
- SONAR
- Positioning and navigation
- ROV cameras
- Data archiving

2.1.3.1. Lights

An analysis of the Sub Atlantic Comanche power and control interfaces was necessary to determine the types of light that could be installed. Based on analysis of the ROV and a survey of lighting systems, there were several findings:

- Input Power: 300VDC is nominal.
- ROV Dimming Control: Two available dimmer controls with space to support one additional dimmer card. Each dimmer card can control two lights with a nominal rating of 250 watts each or 500 watts per card. Each control circuit is ground fault protected. External light pod provides external fuse access and cable distribution for four lights.
- New light emitting diode (LED) technology almost doubles the light output per unit power input and has the added benefit of being extremely shock tolerant. The decision was made to use LED lights.
- Basic illumination of the survey and work areas requires a minimum of four lights on two separately controlled circuits.
- Six lights on three separately controlled circuits provide optimum illumination with two of these lights also serving as functional onboard critical spares.

To augment the basic design criteria, only LED type underwater lights were considered. In terms of illumination performance, the DSPL Matrix 1 was judged superior when compared to the ROS QLED3. In addition, using an internally controlled dimming feature precludes limitations imposed by existing ROV circuitry. However, in this case, higher unit cost and availability led to the selection of the ROS QLED3.

2.1.3.2. Scaling Lasers

An analysis of the Sub Atlantic Comanche power and control interfaces was completed to determine the laser interface requirements. The results of that analysis determined the following:

- Input Power: 24VDC nominal. Lasers should draw no more than 200 ma each
- Operating temperature range without integral heaters of -10° C to 50° C.
- Control: Board control relays -- one relay shall control both lasers.
- Interface access from the vehicle oil filled J-Box using an oil filled cable.
- Lasers would be turned on/off as needed. Typically, lasers would not remain in a powered on state, but only briefly switched on in order for the topside operator to “scale” a target on the fly.
- Adjustable mounting brackets were key component to dual laser parallel mounting.

To augment the basic design criteria the following laser selection criteria was derived:

- Few vendors manufacture underwater laser systems. Both US and European vendors that met the Basic Design Criteria were considered.
- Line beam optics as opposed to laser dots offer a significant advantage, but few vendors provide this as a standard option, so the merits of both optic types were considered.

Very few vendors offer much in the way of a standard underwater laser configured for ROV use. To meet the laser to ROV interface criteria and performance, a custom design made up of standard parts was needed.

- Sidus Systems quoted a custom configuration at a reasonable cost but required a substantial lead time.
- There were no spares ordered for this item. If the laser failed, the operator would use a measuring reference carried by the manipulator to perform the scaling function.
- Seatronics SeaLaser provides greater power but is likely overkill for the application. The Seatronics unit also required about 20 seconds to reach full beam intensity.

The Sidus Systems laser was selected for this Demonstration.

2.1.3.3. SONAR

ROUMRS was equipped with SONAR as an aid to navigation. SONAR was necessary for range resolution-capability to resolve a specific sized target. Dual-frequency capability combines the advantages of a high- frequency, high-resolution scan at short ranges with the lower-frequency, longer-range useful for navigation and obstacle avoidance. There are no US manufacturers for digital mechanically scanned dual frequency SONAR. The selection of the scanning SONAR acknowledges that the new, high-resolution, multi-beam imaging SONAR are a superior alternative to the mechanically-scanned SONAR, despite the higher integration cost (Ethernet) and higher unit cost.

An analysis of the Sub Atlantic Comanche power and control interfaces was completed to determine the SONAR interface requirements. Findings included:

- Input Power: 24VDC nominal. Power switched at relays in ROV POD from topside console command
- Interface access from the vehicle oil filled J-Box
- RS232 telemetry (vehicle can also support RS485 but factory wired for RS232)
- Existing brackets and connector interfaces directly support Triton Super Sea King SONAR.

The Triton Super Sea King SONAR was selected for this Demonstration.

2.1.3.4. Positioning and Navigation

The precision goals for positioning and navigation of ROUMRS were (+/-) 2.5 meters at the water surface and (+/-) 5 meters underwater. Neither Global Positioning System (GPS), nor ultra-short base line (USBL) navigation system were purchased for the Demonstration. However, the surface vessel selected was equipped with GPS and a USBL system was leased for the ROUMRS Demonstration.

Surface vessels navigated using a Trimble GPS on the surface, and the ROUMRS ROV was tracked underwater using an acoustic USBL system. USBL uses an integrated transducer array mounted on a pole at the bottom of the RSV. The surface vessel selected as the RSV was equipped with a GPS system that met the +/- 2.5 meter accuracy as required in the basic criteria listed in Table 2-1 and no other GPS unit was needed to be leased.

The USBL transducer array measures the underwater distance to the ROV from the RSV by the acoustic travel time. Direction was determined by measuring the phase shift of the acoustic reply from a transducer on the ROV as seen by the transducer array. This supplies the ROV operator with the distance and direction to the ROV. This, in turn, is referenced to the shipboard GPS system mounted onto the RSV.

Initially, there were difficulties associated with the navigational positioning of the ROV. Software glitches prevented the operators from knowing the actual location of the ROV due to a failure of the various software systems to transfer the GPS information from the RSV to the ROV and to the digital recording software. During this brief period, bearing and distance of the ROV from the RSV was recorded. The software issues affecting GPS positioning were corrected by uploading programs that enabled the components to send, receive, and record the positioning information.

An analysis of the underwater navigation requirements for ROUMRS determined that ROV positioning referenced from a boat or moored vessel in relatively shallow coastal water was best achieved by using a USBL acoustic navigation system. Long baseline acoustic systems were also considered, but the additional setup time, personnel training, and cost outweighed the accuracy benefits. An analysis of the Sub Atlantic Comanche power and control interfaces was completed to determine the SONAR interface requirements. Findings included:

- Input power: 24VDC nominal-available for trickle charging beacon batteries
- Power interface access from the vehicle oil filled J-Box
- Topside equipment interfaces for recording, GPS, compass, roll, and pitch sensors

Additional details that should be considered regarding the navigation and location of the ROV while using USBL include:

- Position and Slant Range Accuracy: Relative measurement of accuracy is entirely dependent on ship motion, GPS, range, ambient noise, and other factors affecting acoustic data transmission. This is not indicative of the recorded position accuracy, which is a result of the total system bias affecting overall position accuracy.
- Hydrophone: Hydrophones that are more sophisticated integrate sensors such as roll/pitch and heading to further reduce errors and latency issues.

2.1.3.5. ROV Cameras

The ROV was equipped with three cameras. There is a camera placed on the port manipulator, and two cameras mounted on the pan and tilt assembly of the ROV. The primary selection criteria determined by the ROUMRS Team for ROV cameras was to provide the operator with the best possible imaging suite at reasonable cost. High Definition Television (HDTV) cameras were not considered in this evaluation due to their significantly greater unit cost, recording cost, and difficulty with integration to the data archive system. It is important to note that the camera module used can be switched between color and low light black and white modes.

In addition:

- All cameras would use the same video signal format-National Television System Committee (NTSC), which is the standard for North America, having 30 frames per second and using 525 horizontal lines.
- All cameras would be color instead of black and white to aid in target identification.

SeaMax-WA was selected as the ROUMRS camera. SeaMax-WA has domed port instead of flat port optics. Domed ports on wide angle lenses produce less distortion on the edges than flat ports. SeaMax-WA uses an f1.2 lens when coupled with a low light sensitivity camera module produces a usable image (less grain) at lower light levels. Zoom cameras require substantial interface features to the ROV and topside controller-namely zoom, focus, and iris but there are also a host of other parameters that can be adjusted to fine tune the camera to the imaging application.

2.1.3.6. Data Archiving

The ability to collect and record data during ROUMRS operations is a basic design criterion. High level data archive requirements for ROUMRS were developed to preserve the digital information. These requirements were:

- Automated file management and distribution to reduce operator labor associated with manually copying large numbers of video files
- Record NTSC video from 2-channels with integral 4-channel video input switching capability
- Simultaneous and synchronized recording of video and audio channels
- Option to upgrade to 4-channel video recording
- Record 1-channel of audio
- Record 1-channel of analog data
- Records as Windows Meta Files (WMV) or MPEG2
- Scalable video quality
- Full video resolution still video frame grabs for digital still images
- User definable file size limits
- Online video log and video eventing features
- Integrated video overlay
- Input 1-serial string of positioning data
- Supports future video formats (HDTV)
- Record to wide variety of commercial recording media: CD, DVD, USB storage, SCSI storage, SCSI tape backup, and network attached storage
- Shuttle controller on playback
- Free viewer distributed with all media
- Sufficient onboard memory to record 24 hours of 2 channels video and audio

- Flat screen monitor (20”), keyboard, and recorder shuttle control

VisualSoft Visual DVR was selected as the data archive system because it was the only system found that met the general requirements, is widely used by US based ROV companies, is supported out of Houston Texas, and was immediately available for purchase or hire.

2.1.4. Salvage Basket System

The Salvage Basket System provides a means for ROUMRS to recover UWMM safely and efficiently. It also contained propellant grains and provided a container that could be floated using a lift bag and towed to a designated location (i.e., the DSV) where it could be lifted out of the water and placed on a barge, dock or beach.

The Salvage Basket System consists of the following equipment:

- Salvage basket – a purpose built basket with an internal volume of approximately 140 ft^3 and a loaded capacity of 2,000 lbs (subsea). Includes ROV hopper cargo transfer interfaces and provides containment for 3/16” diameter particles (e.g., propellant grains, bulk explosive particles).
- Lift bag – includes the purpose built 3,000 lb rated air lift bag for raising the salvage basket off the bottom, provides lift to the surface, and maintains sufficient floatation for the salvage basket as it is towed to the processing location
- Lift and tow rigging
    - Purpose built rigging that connects the air lift bag to the salvage basket
    - Purpose built rigging that is used to tow the salvage basket/inflated lift bag and lift the salvage basket onto the DSV

The salvage basket is designed as a containment vessel for recovered UWMM and associated debris. The basket will carry objects as large as 55-gallon drums; large caliber artillery rounds, bombs, and contains objects as small as 3/16” in diameter. It has ROV-specific interfaces including alignment features, ROV friendly rigging, and spring loaded latching pins. Load-distributing pads and a baffle were built into the basket to minimize movement of material placed in the basket and minimize seabed penetration or damage.

The salvage basket is designed to be lowered to the bottom using a down line from a surface support vessel; filled by the ROV, which after filling attaches an air lift bag; sent to the surface using the lift bag, and then towed to a recovery position by a small craft. The salvage basket is designed to support the weight of the ROV in-water and is subject to the same dynamic loading criteria as the ROV for forces applied during launch and recovery per the

American Bureau of Shipping (ABS) Rules for Building and Classing Underwater Vehicles, Systems and Hyperbaric Facilities (App 4, 9.3.4).

2.2. Explosive Hazard Demilitarization System (EHDS)

The EHDS was designed to demilitarize and eliminate the explosive hazard associated with recovered munitions and MDEH, resulting in MDAS and released for local recycling. The process involves remotely cut open recovered munitions exposing the explosive (energetic) fill and subsequently thermally treating the exposed energetic compound using convection heat in a manner that decomposes the energetic non-explosively. Thermal decomposition does not generate explosive gases.

The EHDS is designed to maintain temperatures well below the ignition temperature of the exposed explosive filler, and result in nonhazardous residues. Operators, in real-time, remotely monitor temperature of the RCBO to verify temperatures required for decomposition are reached and maintained, and ensure temperatures that could cause a detonation are not reached.

The subsystems comprising the EHDS include: the silicon controlled rectifiers (SCR), the RCBOs, water cooled band saws, an x-ray system and shipping container enclosures. Figure 2-1 outlines the EHDS process, and Figure 2-2 shows the DSV layout and Quantity Distances of Concern.

2.2.1. EHDS Explosive Safety Considerations

To minimize potential explosive hazards to the public, demilitarization activities (i.e., cutting and treatment) were performed within a shielded, 20-foot ISO steel shipping containers. Operators on the EHDS monitored the process from behind blast and fragmentation barriers designed to withstand and redirect the forces of an unintentional detonation. As an extra safety measure and for additional structural strength, steel plating was built into the floor and walls at specific locations on the shipping containers that housed the EHDS.

EHDS's operational hours and those for ROUMRS were also tailored to minimize the impact to public recreational activities. Application of DoD's explosives safety criteria helped ensure the public was protected from the explosives hazards associated with various quantities and types of munitions (DoD 2009). Of these criteria, one is the establishment of Explosive Safety Quantity Distance (ESQD) arcs, or explosives safety zones. ESQD vary in radius based on maximum fragmentation distance and the net explosive weight (NEW) of munitions present at a given location. An ESQD is determined based on either a planned NEW — normally the maximum NEW that would be allowed — or on the actual NEW present. During the Demonstration, ESQD was applied when recovered munitions were placed on the DSV deck. The ESQD arcs for this Demonstration were reviewed and approved by both the USATCES and the DDESB. The ESQD arcs are discussed in more detail in section 3.2.3.

For safety reasons, positive identification of all munitions was required prior to processing. With some exceptions (i.e., SAA, fuzes), recovered military munitions were X-rayed to ensure they did not contain a liquid fill.

2.2.2. Control Systems

The RCBOs' temperatures and heating rates were controlled separately, with temperature monitored and recorded throughout the treatment process (i.e., heating and cool down). The control panels and power distribution equipment (480 VAC Panel board, step down transformer, and 240/120VAC load center) for the EHDS' six RCBO ovens were designed and built to facilitate control of temperatures and each RCBOs' heating rates. Because EHDS was designed to operate on a vessel, with floating grounds, the electrical systems were designed according to Institute of Electrical and Electronics Engineers (IEEE-45) as well as ABS, Rules for Building and Classing Steel Vessels 2009, Section 4. The pertinent loads were not required to be treated as "Essential Services" or to be necessary for "Minimum Condition of Habitability." As part of the Demonstration, detailed control panel fabrication and as-built drawings were generated.

The custom SCR panels for the EHDS system included:

- Control of six RCBO ovens with three-phase 460 VAC, delta configured heating coils
- Coordination of starters and an associated custom built control panel for six oven fans and two ventilation fans
- Engineering design to evaluate the electrical loads associated with the oven container and associated remote control panel and container
- Engineering design for the size of the generator required to drive these loads, as well as wire size, and breaker size for associated electrical loads.

2.2.3. Shipping Container Enclosures

ARA modified three standard 8 by 20 foot ISO shipping containers to house the EHDS system. These containers housed EHDS's control room, RCBOs, and remote cutting bay. The control room was fitted with two inches of mild steel plate to provide frontal and overhead protection for the operators per DDESB requirements.

The construction and steel plate for the control room, the RCBO container, and the remote cutting bay involved bolted construction and American Welding Society (AWS) D1.1 welding, exterior surfaces SP10 blast and painted epoxy. These containers were test fitted in the ship, with each container fixed with lifting lugs.

The RCBO Container design also included:

- Electrical supply/input for six RCBOs that were mounted in the steel weather housing structure
- Two 5,000 cubic foot per minute exhaust fans with a 10 ft exhaust stack for each fan
- Container designed to ship complete with flanges to bolt the exhaust fan and all hardware
- Mechanical drawings

2.2.4. X-Ray

Munitions identifications occurred at the stern of the DSV, (Figure 2-1 shows the DSV layout and Quantity Distances of Concern). Once the salvage basket was brought on deck, the munitions were sorted, segregated and braced to keep them from moving. After the munitions were visually identified and logged, they were x-rayed to ensure they did not contain a liquid fill that might indicate the presence of chemical fillers that cannot be treated by the EHDS. None of the UWMM recovered contained a liquid fill.

2.2.5. Remotely Operated Water Cooled Band Saws

The remotely operated, water-cooled band saws used to open UWMM recovered by ROUMRS were supplied by the subcontractor, Golden West. After remote cutting operations, exposed segments of explosive-filled munitions were immediately placed in the RCBO for treatment. This minimized the potential for the formation of explosive salts. The remotely-operated band saws were provided with a continuous water supply to cool the saw blades and the munition being cut. The RESS produced recommendations and they were implemented while assembling the EHDS. As part of this, the cutting station consisted of 2 saws placed a minimum of 81 feet (K18)[1] from the remote operations container. This distance is based on calculations for protection that must be provided the operators in case of a detonation. A fragmentation barrier of mild steel 2 inches thick (exceeding the 1.82 inch required) provided frontal and overhead protection to the remote operators, located outside the K18 Distance. See Figure 2-2 for exclusion distances. Spent blade cooling liquid from remote cutting operations was recycled to the extent possible and was ultimately placed into a RCBO for treatment of explosive MC present.

[1] K18 is the factor in the formula $D=KW^{1/3}$ used in quantity distance determinations where D represents distance in ft and W is the net explosive weight (NEW) in pounds. The K-factor is a constant and represents the degree of protection that is provided.

2.2.6. Radiant Convective Batch Ovens

Each of the six RCBOs was heated by an electric, radiant-heating, element designed to achieve 650° F (345° Celsius (°C)) air temperature. A recirculation fan was used to increase airflow, improve convection heating and promote even heat distribution. Munitions' segments (cut munitions) with exposed explosive MC filler were placed into the ovens so that maximum airflow could be maintained. The required thermal heating (soak times) and temperatures depended on the explosive MC fill, the surface area of the exposed explosive MC, and the thickness of the munition body segment that surrounded the exposed explosive MC. Remote operators monitored real-time temperatures by verifying that adequate times versus temperature ratios were reached for the decomposition of the specific explosive being treated.

The preset temperatures and soak times are based on Technical Manual (TM) 9-1300-214, Military Explosives, however, these were adjusted during the Demonstration to optimize thermal treatment. All treatment systems were monitored remotely during operations using Type J Thermocouples and a data logger. Only explosive MC with compatible treatment times and temperatures were placed in the same RCBO, because the mixing of explosive MC and treatment temperatures could lead to an unintentional detonation.

The RCBO were designed as follows:

- Each of the oven enclosures was built with a 6-inch thick insulated construction with 18 gauge stainless steel interior construction and 10 gauge aluminized exterior construction.
- The dimensions of the oven were 60 inches long x 26 inches high x 42 inches wide (sitting on a 16 inch steel frame for a 42 inch overall height). Inside the oven chambers are 48 inches deep x 10 inches high x 30 inches wide.
- A single, 6-inch thick hinged access door, including an electromagnetic latch and spring loaded hinges, was equipped to each oven.
- Each oven was equipped with one electric heating element to achieve 345° °C air temperature.
- Each oven was equipped with one supply air recirculation fan for convection heat and even heat distribution.

Treatment entails raising the temperature of the RCBO to the level needed to irreversibly break the exposed explosive MC's chemical and molecular bonds without reaching the ignition temperatures (non-explosive decomposition temperatures). The minimum non-explosive decomposition temperatures for most explosives range from 200 to 250°C. Slightly higher temperatures may be used to increase the decomposition rates; however, the intent is to maintain temperatures well below the ignition temperature of the explosive MC being treated. As examples, between 295 and 300°C for TNT, 255 to 260°C for RDX, and 230°C for nitrocellulose (NC)(present in propellant). The time at a given temperature varies based on the mass of energetic MC being treated. The RCBO operators, who are located in a protected control room container on the DSV, monitor the temperatures and verify that adequate temperatures (determined from the time versus temperature curves for the decomposition of the specific explosive) have been reached and a non-explosive condition has been achieved.

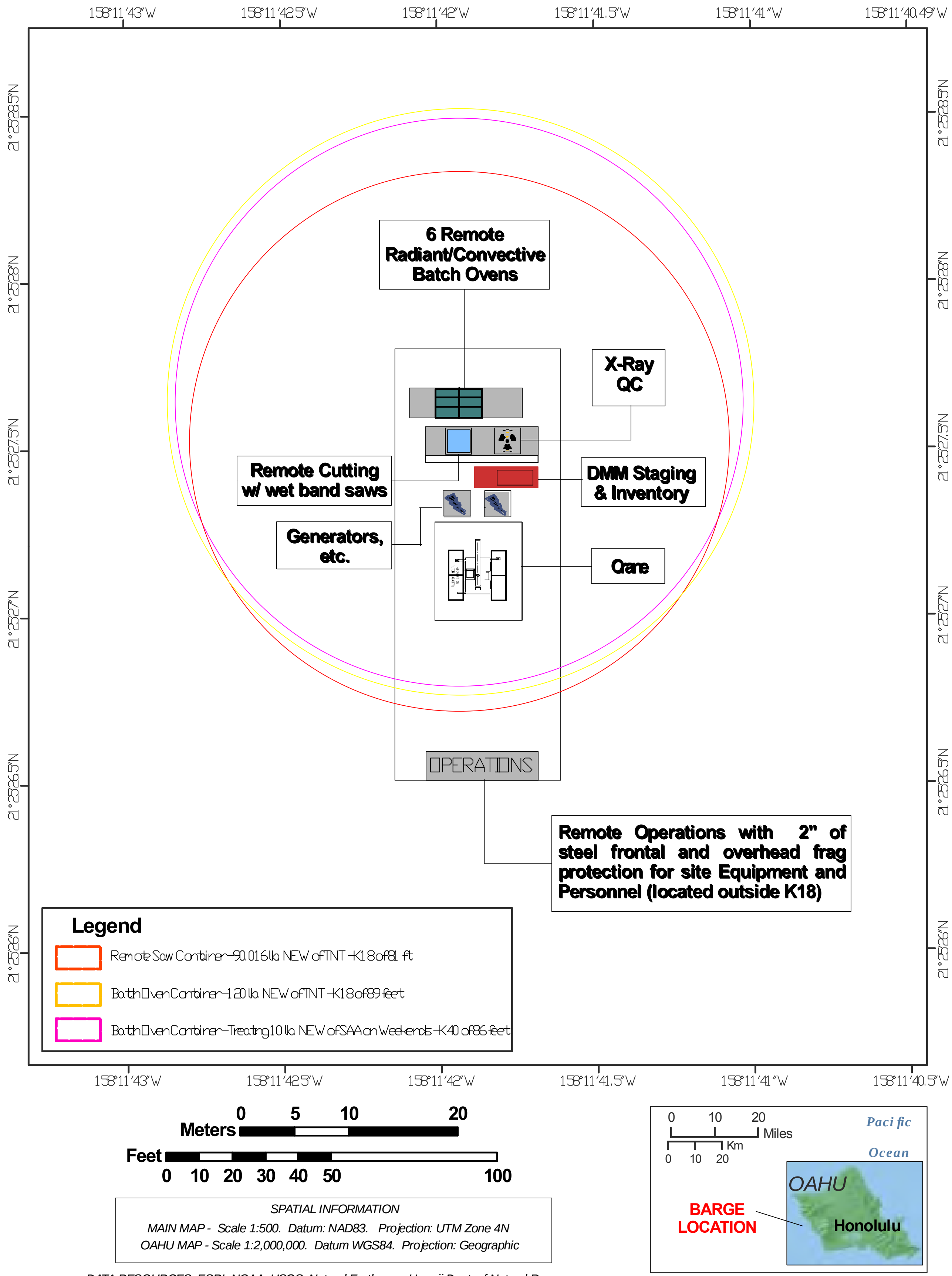
The slow decomposition of NC begins at approximately 160°C. At the temperature of approximately 210°C, non-explosive decomposition takes approximately 15 minutes. However, it may take as long as an hour to reach the target temperature. The amount of time depends on the mass and surface area of the explosive MC being treated. NC, which will begin to decompose once the temperature reaches 160°C, will continue to decompose as the temperature is increased to the target temperature of 210°C. Similar to TNT, Explosive D, which has an ignition temperature of 300°C, begins decomposing at a rapid rate at approximately 250°C.

The temperatures for the RCBO are carefully controlled to ensure that temperatures high enough to break the molecular bonds of explosive MC are reached without causing lead or other metal vapors to be released. Lead vaporization can occur at temperatures of 361°C, which is much higher than the temperature needed to degrade most explosives.

FIGURE 2-1

DSV LOCATION AND

QUANTITY DISTANCE



DATA RESOURCES: ESRI, NOAA, USGS, Natural Earth.com, Hawaii Dept. of Natural Resources

FIGURE 2-2

EHDS PROCESS DIAGRAM

1 of 2

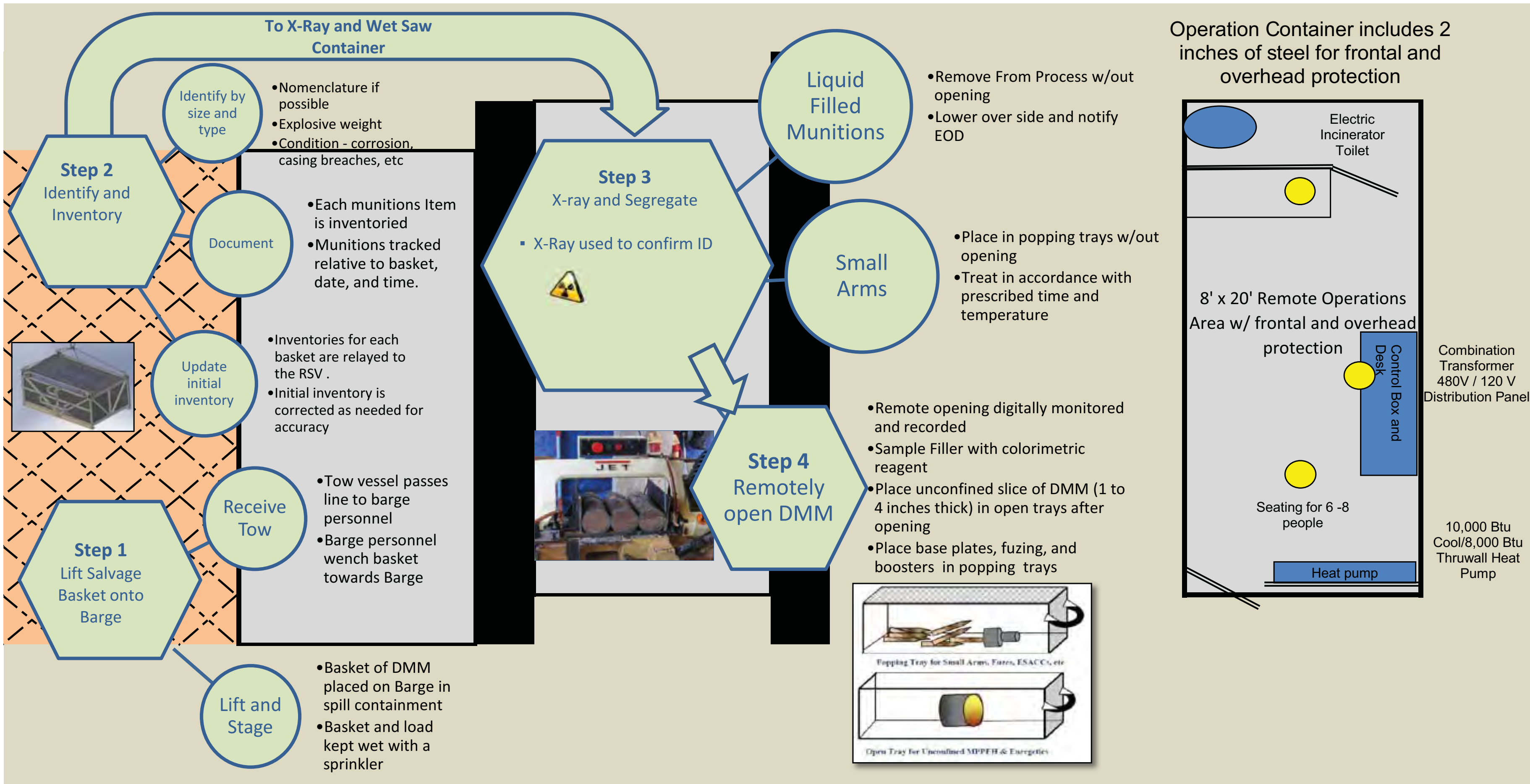
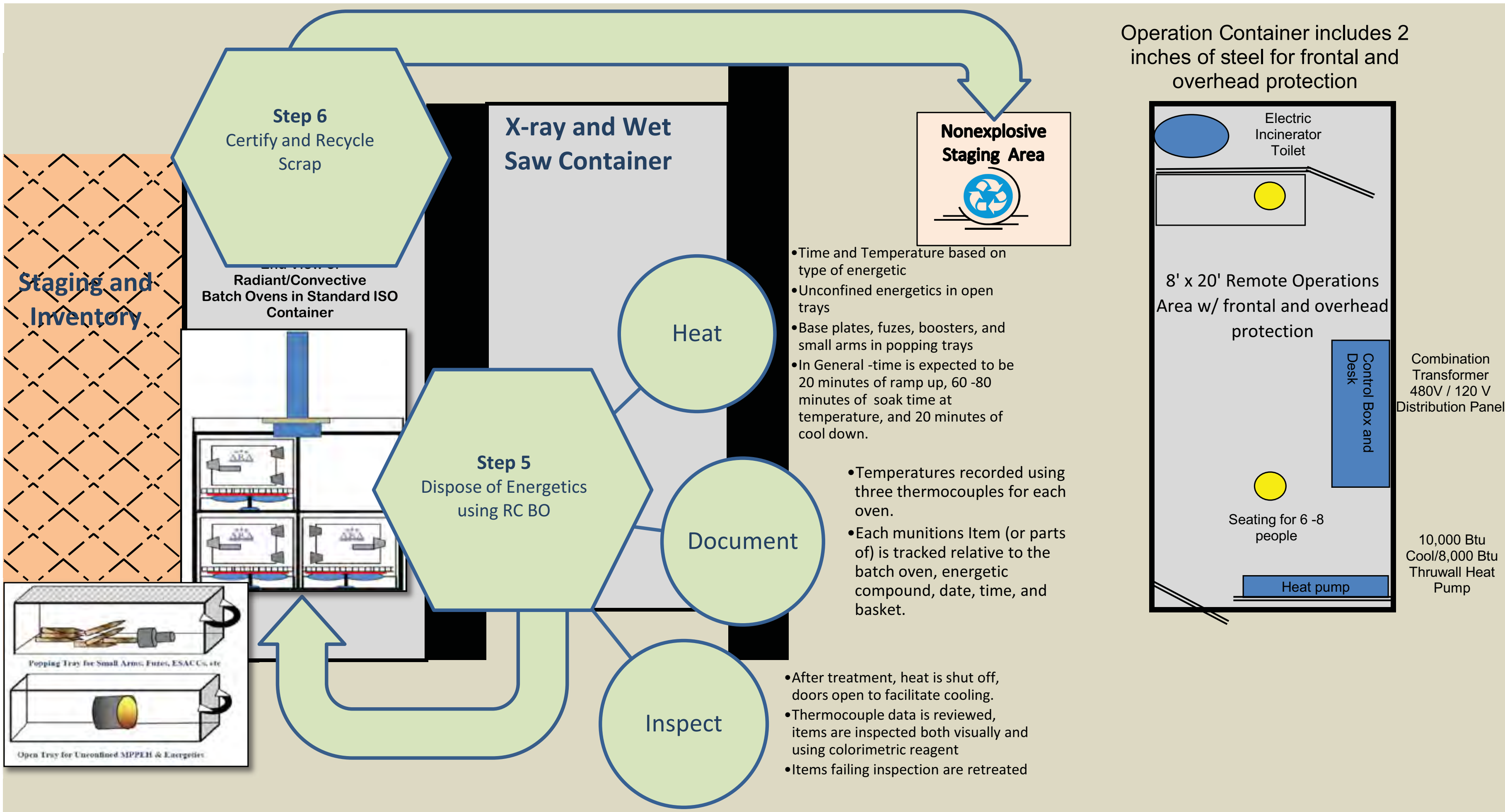


FIGURE 2-2

EHDS PROCESS DIAGRAM



3. DEMONSTRATION DESIGN

3.1. Conceptual Experimental Design

Rather than the traditional methods of using UXO-qualified personnel who are also commercial divers, a work class ROV was selected. Given use of the ROV, tools were developed to attempt to recover UWMM from the seafloor and bring it to the surface for disposal. ROUMRS and EHDS were towed to and moored at Ordnance Reef (HI-06). Using the results of previous munitions surveys (i.e., USACE's survey for FUDS determination, NOAA's screening level survey), and NOAA's CAMIP, the Demonstration team was able to select specific work areas, and then selected and attempted to recover UWMM. This allowed the Demonstration team to minimized the impact on the environment and vigorously test ROUMRS's various subsystems.

UWMM that were recovered were tentatively identified and placed in the salvage basket to be brought to the surface. Once on the DSV, munitions were inspected, catalogued, and processed (remotely cut, treated) by the EHDS. Use of ROUMRS alleviated the need for UXO-qualified divers, reducing potential risks and allowing for 24-7 operations. In effect, the use of ROUMRS would reduce the overall cost of recovery operations for UWMM should they be determined to pose an unacceptable risk. Use of EHDS - a barge-based system - improved explosive safety with minimum effect on offshore activities and without affecting landward operations.

The Army did not require site preparation prior to the Demonstration. However, NOAA did survey coral and other benthic habitats at Ordnance Reef (HI-06) and documented its findings in the CAMIP. The CAIMP documents the challenges associated with avoiding injuries to coral colonies and other benthic habitats in the work areas and the presence, distribution and location of UWMM.

Information on recovered UWMM was digitally recorded and documented on data collection forms, and then the UWMM was placed into the ROV hopper for transport to the salvage basket for subsequent transport to the surface. If ROUMRS was unsuccessful at recovering an UWMM, the munitions' description and location were noted.

A post Demonstration survey of site conditions is by NOAA is underway to compare the site conditions before the Demonstration with post Demonstration conditions (see Section 1.3).

3.2. Pre-Deployment Activities

Development of ROUMRS and EHDS proceeded concurrently. Construction and testing of ROUMRS was conducted at the OII facility in Hanover, Maryland. The construction and testing of EHDS was conducted at Bass Mechanical in Elizabethtown, Pennsylvania. The systems were shipped to Oahu following testing activities for assembly and transport to Ordnance Reef (HI-06).

A variety of regulatory activities were required to be completed prior to deployment and the conduct of the Demonstration.

3.2.1. Permitting and Regulatory Activities

In addition to obtaining a right of entry to allow access to the work area, it was necessary to coordinate with several agencies to obtain input waivers, site access and permits, as required by:

- Magnuson-Stevens Fishery Management and Conservation Act [Essential Fish Habitat]
- Fish and Wildlife Coordination Act of 1934, as amended
- Section 7 of the Endangered Species Act of 1973 as amended
- Section 106 of the National Historic Preservation Act, of 1966 as amended was coordinated with:
    - Hawaii State Historic Preservation Office
    - Office of Hawaiian Affairs
    - Association of Hawaiian Civic Clubs
    - Hawaiian Civic Club of Waianae
- Coast Zone Management Act
- Department of the Army Permit, Section 10, 33 USC 403
- Resource Conservation and Recovery Act – Based on the new technology (EHDS), a research and development Hazardous Waste Permit was secured in lieu of a 90-day emergency disposal permit.

The following permits from the Department of Land and Natural Resources were not required:

- Mooring Permit
- Special Activities Permit, Coral and Live Rock Taking
- City Conservation District Use Permit

Waiver from air permit requirements: The development of emissions estimates was an important part of the EHDS pre-Demonstration activity because such estimates are required to determine whether an air emissions permit is required. Based on the munitions believed present on the reef, the energetic materials were anticipated were: NC, RDX, TNT, Composition B, tetryl and Explosive D (ammonium picrate) (Mitchell, 2010). Although decomposition data is not available for these materials when treated in a manner (air environment at atmospheric pressure) like the EHDS would treat them. However, an extensive body of data is available on the decomposition pathways and products of these materials derived under conditions that are applicable to the EHDS system.

Several findings applicable to the potential EHDS emissions were found:

- Nitrogen oxide (NO) was a major final decomposition for all of the materials, and carbon monoxide (CO) was a major decomposition product for all except RDX for which CO was a minor decomposition product. Carbon dioxide (CO_2) was a major decomposition product for TNT, and a minor one for the other materials. When reported, nitrogen dioxide (NO_2), hydrogen cyanide (HCN), soot and small hydrocarbons were always minor decomposition products.
- Energetic materials (explosive MC) in the same explosive category that also have similar structures have identical decomposition pathways and final degradation products.
- The binders and performance and stability modifiers that are sometimes found in energetic materials generally decompose before the energetic compounds. The presence of binders does not seem to significantly influence the final decomposition products.
- Temperature and pressure can influence the relative ratios of the final decomposition products, but the mix of products tends to remain the same. The effect seems to be directly related to the percentage of the energetic compound that is in the vapor state, rather than of the energetic material itself. That is, the higher the percentage of the energetic in the vapor state, the higher the effect of temperature and pressure on the distribution of the final decomposition products.
- In the one instance where the decomposition was studied in both reactive (e.g., O_2) and inert environments, the reactive environment produced more CO and NO and less CO_2 and NO_2 than the inert environment.
- When the decomposition process goes to completion, aromatic and polycyclic decomposition products have never been reported for any of the energetic materials present in the UWMM present at Ordnance Reef (HI-06). In fact, the highest molecular weight hydrocarbon reported in the literature reviewed was ethylene, which was present in very small quantities. The absence of higher molecular weight organic materials is consistent with the reaction pathways by which the energetic materials thermally degrade.

Table 3-1 contains estimates of the decomposition products in pounds of CO, NO and NO_2 produced from each pound of energetic material treated in the EHDS. These estimates were based on the following assumptions:

- CO, NO and NO_2 are the only decomposition products that are produced in meaningful quantities when (a) the EHDS decomposes the energetic materials, and (b) the heating cycle is long enough to completely decompose the energetic materials in the RCBO.
- All of the carbon in the energetic material is released as CO. This is a very conservative estimate because some of the carbon is always

released as CO_2. In one case, CO_2 was the major carbon-based decomposition product.

- For energetic material, 85% of the nitrogen is released as NO, with the remainder released as NO_2. This is a reasonable assumption, because NO was always the major nitrogen-based decomposition product, while NO_2 was always a minor one. It is also reasonable because some of the nitrogen will likely be converted to nitrogen gas.
- The energetic compounds in fuzes, boosters, SAA and similar munitions can be ignored because they will represent less than 1% of the total weight of the energetic materials treated and the decomposition products will be identical to those for the corresponding unconfined energetic compound.
- The metals in the munitions parts and slices will not vaporize, remaining in the oven trays. This is a reasonable assumption because studies have shown that the metals in munitions casings and parts do not vaporize even when the munitions are detonated.

Table 3-1: Decomposition Products from the EHDS

Energetic Material	lbs of Decomposition Product Produced per lb of Energetic Material Treated in the EHDS		
	CO	NO	NO_2
NC	0.667	0.175	0.052
RDX	0.378	0.597	0.178
Tetryl	0.820	0.462	0.138
TNT	0.863	0.292	0.087
Ammonium picrate	0.677	0.356	0.106
Composition B (TNT/RDX mix)	0.566	0.471	0.141

Based on the calculations and other information provided, the State Department of Health determined that the EHDS operations were exempt from air permitting requirements. This was partially based on the assumption that the EHDS would operate approximately 8-hours per day over a 19-day period.

3.2.2. ROUMRS Pre-Deployment Activities

The ROV was initially tested at the Sub Atlantic factory in Scotland before it was shipped to the United States. Assembly of the ROV with the various components for ROUMRS was performed at OII, with testing conducted at the large water tank at OII in September 2010. The tank testing was designed to test as many of the ROUMRS performance characteristics as possible prior to deployment for the Demonstration. The tank test successfully tested the systems capabilities and resulted in several significant findings:

- Manipulators:

  - The port manipulator was damaged during the Demonstration. The manipulator came in contact with the vehicle frame causing a pin joint to loosen and subsequent movement caused the manipulator upper frame member to bend. Kraft Manipulators had never been placed on this ROV model before and the position of the vehicle frame in relation to the position of the arms was the primary cause of the damage. To remedy this design flaw, the vehicle frame was modified and the manipulator arm was repaired.
  - Stowing the manipulators was a problem. Neither manipulator is equipped with check valves to hold the arms in position when hydraulic pressure is off or disabled. In this state, the arms are not constrained, which is a hazard and could result in damage during ROV launch or recovery. A stowage bracket was designed and installed on the ROV as a remedy.
  - Manipulators are precision instruments that require a trained operator. Both the FB and the NFB arms have numerous functions and modes of operation. The damage to the port arm was also the result of a lack of familiarity with the manipulators.
  - Operation of the starboard manipulator (FB) solenoid valve was not smooth. The valve did not to open when hydraulic pressure was applied, and the valve remained open when hydraulic pressure was off. The valve was disassembled and repaired.

- Several ROV frame modifications were required:

  - The frame interfered with the free motion of the manipulators, as described above. This restriction became more apparent when the arms were used to pick up long objects and put them in the ROV hopper. The interference first became apparent when raising the shoulder joint to an elevation sufficient for the munition to be placed in the ROV hopper. To remedy this, both sides of the forward section of the ROV frame were trimmed back to eliminate any obstruction. In addition, this area was reinforced with aluminum structure as required to support the forward bumper and light bar.
  - The frame required reinforcement where the aft part of the ROV sagged due to the weight of the hydraulic pumping unit (HPU) and transformer. To remedy this, an aluminum bar was fabricated for reinforcement.
  - Newly installed aluminum equipment was delivered without zinc anodes installed to protect the aluminum from corrosion when immersed in seawater. Zinc anodes were installed on the pan/tilt and tilt mounting brackets, manipulator mount, hopper frame and hopper actuator bracket.

- Flotation and stability also required the following modification:

  - Floatation and ballast required adjustment of their placement to allow proper buoyancy and trim. The existing floatation had excess buoyancy in freshwater (approximately 40-60 lbs) that translates into more buoyancy in saltwater than the vehicle thrusters can overcome. To trim the vehicle out

for the Demonstration, lead ballast was shifted aft and floatation was added forward.
  - Weight was redistributed across ROV frame, and additional flotation was added to bring the ROV into proper trim and eliminate pitching motion.

- Issues with the ROV hydraulic system included:

  - Installation of common steel rather than stainless steel due to long lead times for stainless steel fittings. All were subsequently replaced with stainless steel fittings.
  - Hydraulic cylinder on the ROV hopper actuator was damaged during assembly and required replacement with a spare cylinder.
  - Hydraulic lines between the ROV hopper cylinder and the ROV were difficult to change, so quick disconnect fittings were installed. This reduced overall trouble/repair time for the actuators.
  - Manufacturer-developed hydraulic system was poorly documented, as were the as-built features. This was remedied by placing labels on the lines, and developing a schematic drawing of the hydraulics.

- The suction pump assembly required the modifications below:

  - Interface between the manipulator arms and the suction pump hose was inadequate, and a grip for the hose was developed.
  - Retainer for the suction pump hose was inadequate, and a better hose retainer was developed.
  - Suction pump inlet seal came loose and needed a threaded interface for an adequate hold.
  - Filter canister to hold particles captured by the suction pump was developed.

- The salvage baskets required these modifications:

  - Inner door springs were removed and replaced with upgraded (stiffer) springs to provide sufficient tension.
  - Tolerances on the shackle hole diameters were too small, so holes were widened by 0 .050 inch.
  - Outer door retaining pins, as designed, were difficult for the ROV to release or lock in position. The T-handles were reoriented, and the existing springs were replaced with ones with lower force.
  - ROV alignment features when the ROV hopper was dumped.
    To remedy this, alignment features that permit the ROV to quickly center the ROV hopper on the salvage basket swing doors was added.
  - Zinc anodes were installed on the salvage basket frame, liner, outer, and inner doors to prevent corrosion.

After the pre-Demonstration testing was concluded, the ROV and baskets were deemed capable of operating as designed, and with minor modifications, would be able to perform the anticipated work at Ordnance Reef (HI-06).

3.2.3. EHDS Pre-Deployment Activities

Bass Mechanical (Bass) built the EHDS system components into three ISO shipping containers and fabricated and modified ROUMRS' salvage baskets. The EHDS testing was designed to evaluate as many of the EHDS performance characteristics as possible prior to deployment for the Demonstration.

Bass received the 20-foot ISO shipping containers in February 2011 and modified them. The EHDS' controls and RCBO were tested in April 2011. Both SAA and smokeless powder were thermally treated in RCBO. Flashing (ignition) and off- gassing was observed during thermal treatment. This indicated that the ovens, as originally designed, acted as a sealed and closed space allowing the rapid creation of gasses and over pressure that caused the RCBO's doors to fly open when a flash occurred. ARA removed the RCBO door seals that made the ovens air tight to allow the ovens to vent; thereby, reduce the likelihood the doors would be thrown open.

After conducting pre-Demonstration tests, ARA determined that the EHDS controls and RCBOs were capable of operating as designed and, with minor modifications, would perform as designed during the Demonstration.

3.2.3. Explosive Safety Planning

The DSV location and the positioning of the EHDS's components (i.e., RCBO, band saw and operations station) on the DSV were carefully planned to minimize potential explosive hazards to the public and personnel involved in the Demonstration. This resulted in the Demonstration requiring a larger platform than originally anticipated to maintain safety separation distances on the barge.

The EHDS activities, described in Section 2.2, and all explosives safety measures including the ESQD were reviewed and approved by both the USATCES and the DDESB prior to the Demonstration. An ESQD of 3,727 feet was required during remote cutting operations. Personnel were kept at the predetermined distances during EHDS operations. This distance was based upon an 8-inch M103 projectile (MGFD). Research and the results of previous investigations, identified 8-inch projectiles as the munitions with the greatest fragmentation distance that were likely to be recovered. Had munitions with a greater fragmentation distance been recovered, the Army would have adjusted the DSV position to ensure public safety. During the Demonstration, munitions with a greater fragmentation distance or NEW greater than the 8-inch projectile were not encountered.

Exclusion zones were established for each operation based on the minimum separation distance (MSD) for the MGFD. When munitions containing HE were being processed, an ESQD of 538 feet for essential (e.g., UXO-qualified workers performing the demilitarization) and 3,727 feet for nonessential personnel (e.g., public) were maintained around the DSV (ARA, Incorporated, 2011) (Figure 2).

Locally contracted, small watercraft kept unauthorized boats out of the safety zone (ESQD). The Army positioned the DSV to minimize the impact of the required ESQD on the public (e.g., beach access, traffic on public roads, popular recreational dive locations). Munitions brought on board the DSV that could not be processed prior to completion of the day's operations, were placed back in a salvage basket and staged underwater until the next processing cycle.

During ROUMRS' operations (i.e., launch and recovery, recovery of UWMM, towing of salvage baskets), the Army maintained an ESQD of 254 feet around the ROV, salvage baskets, and RSV for nonessential personnel (ARA, Incorporated, 2011). Given the operational length of the ROV tether, a 500-foot safety buffer was maintained around the RSV to prevent damage to equipment and limit interference by vessels not involved with the Demonstration.

4. DEMONSTRATION ACTIVITIES

ROUMRS and EHDS were reassembled shortly after arrival at Honolulu Harbor, Oahu, Hawaii, the last week of June 2011. The Army subsequently established an operations center at the Pokai Bay Army Recreation Center, Waianae, Hawaii.

All personnel participating in the Demonstration were briefed on the work plan and safety concerns pertaining to the equipment testing. Prior to the Demonstration, ARA developed an Accident Prevention Plan (APP), which USACE safety personnel from POD and POH reviewed and the Army approved. ARA also developed an Explosive Safety Site Plan (ESP) that was reviewed and approved by USATCES for the Army and separately by the DDESB for DoD. Personnel working on the Demonstration reviewed and signed the APP.

ARA divided Ordnance Reef (HI-06) into three work areas, A, B and C (see Appendix A, Plate A-3). The three work areas were created to limit the area impacted by Demonstration activities. Areas with minimal coral densities were selected as anchorage locations for both the RSV and DSV once ROUMRS ROV began dive operations. Video was recorded at these locations to document the initial conditions. The weather was optimal throughout the Demonstration, with very little rain and temperatures in the high 70s to low 80s (°F).

Unforeseen problems (e.g., non-routine maintenance of ROUMRS) were attended to by ARA and OII personnel, who had extensive experience operating and maintain the equipment, were on-site to repair any malfunctions and resolve such problems. Although the Army considered it possible that a UXO could be inadvertently recovered during the Demonstration and that it might detonate, it did not believe such an event probable given the amount of information it already had about the UWMM present. Nevertheless, a UXO-qualified technician tentatively identified each UWMM being recovered prior to its being placed into the ROV hopper.

Procedures for dealing with fuzed UWMM and other unforeseen situations were outlined in the APP. To mitigate the potential damage from an inadvertent detonation, the Army established an ESQD (safety zone) around the DSV based on the DDESB-approved safety submission. During the Demonstration, non-essential personnel were not allowed to enter the exclusion zone, unless cleared by on-site safety personnel.

4.1 Demonstration Field Activities

Field activities were conducted in waters at depths ranging from approximately 20 to 120 feet. NOAA conducted preliminary UWMM mapping to determine the relative risk to corals and other benthic habitats during recovery and related activities. Prior to beginning field activities, the Demonstration team compared selected work areas with information in NOAA's CAMIP. Based on this information, the Demonstration team began its efforts in Area C where NOAA indicated the corals would be least affected.

ROUMRS was used to recover as many UWMM in this work area as possible in the time allotted. (ROUMRS' operational areas are provided as figures at the end of Section 5.)

ARA and associated subcontractors were responsible for implementing BMP throughout the Demonstration and for adhering to the APP and ESP. The protection of human health and the environment were priorities throughout the Demonstration. In consideration of environmental protection, no intentional detonations were planned or performed during the Demonstration.

The Demonstration's ROUMRS activities were divided into distinct munitions recovery-related operations that included:

- Mobilization
- Mooring of support vessels
- Launch and recovery of the ROV
- Launch and movement of salvage baskets
- ROV reconnaissance operations and munitions classification
- Munitions recovery and subsea operations
- Lifting, towing, and recovery of salvage baskets
- Data collection and archiving
- Demobilization.

Vessels working on this Demonstration were operated from Waianae Harbor with field activities occurring at Ordnance Reef (HI-06) south and west of Pokai Bay, and due west of Waianae, Oahu, Hawaii (Appendix A, Plate A-2), at and around latitude North 21 degrees 26 minutes 0 seconds, longitude West 158 degrees 12 minutes 0 seconds. Work area was approximately 3 nautical miles (nm) long in the north-south direction and approximately 1 nm wide in the east-west direction.

The Demonstration began on July 11, 2011, with ROUMRS activities continuing through July 30, 2011 and EHDS activities through August 3, 2011. Working hours on the water were based on 12-hour days that were schedule to begin at 0600 and end by about 1800 hours; however, they were often extended.

To minimize inconvenience to recreational and commercial users of Ordnance Reef (HI-06), the DSV only conducted explosive demilitarization operations that required an ESQD of 3,727 feet, 5 days a week. On weekends, a general safety zone extending between 100 and 500 feet beyond the DSV was maintained, and only SAA were treated. The Demonstration team positioned the DSV so as not to interfere or impede beach access, public lands, traffic on public roads, and popular recreational dive locations.

4.1.1 Mobilization

Equipment was mobilized from the OII Hanover, MD facility and the Bass facility in Elizabethtown, PA to the Island of Oahu in Hawaii via common carrier. An important part of the mobilization was ensuring that the ROV was properly packaged for shipment. Equipment was tested to the extent possible prior to shipping and loading onto a vessel of opportunity. Mobilization included a crewmember briefing (see BMP #2, "Crew Briefing") and a review of all procedures (see BMP#3, "Pre-Operations Checklist") to be performed during field activities.

Upon arrival in Hawaii, a command and control center was established for ROUMRS on the Sea Engineering workboat, Huki Pau. The Huki Pau operated as the RSV. The ROUMRS command center was established in the boat's cabin and housed the ROV controls and communication equipment mounted securely as well as ship-to-ship and ship-to-shore communication capabilities.

4.1.2 Mooring of Support Vessels

Once ROUMRS was at the work site, the ROV was used to survey DSV and RSV mooring locations and locations for placement of salvage baskets. Areas with minimal coral densities were selected for these moorings and placements. The CAMIP was also reviewed to aid in selecting mooring locations, locations for the salvage baskets and for recovery activities. Personnel involved in operations were transported to and from the RSV and DSV at the beginning and close of the workday by small boats from Waianae Harbor.

Work Area C was selected to begin UWMM recovery activities because it contained the most UWMM and was relatively clear of coral and other benthic habitats. The mooring locations for the RSV required sufficient lines to moor in up to 200 feet sea water (FSW). Both the RSV and DSV required sites to place the four-point moorings. The mooring sites selected were examined, with the bottom conditions digitally recorded for future reference, by the ROV and, when the depth allowed, by divers from NOAA and the State of Hawaii prior to placing anchors. Efforts were made throughout the Demonstration to avoid dragging anchors. (During the Demonstration, anchor movements were not observed.) Mooring lines, cables, and chains, were suspended above the bottom to prevent them from impacting the benthic substrate. (Documentation of the bottom conditions followed BMP #4, "Anchorage, Mooring Area, and Staging Area Inspections," during any anchorage, mooring or equipment staging activities on the sea bottom).

Once moored, the RSV was only to be moved once the ROV completed field activities in a given area. However, because the RSV used a four-point mooring system, it was able to move effectively across much of Work Area C without re-mooring. ROUMRS departed the site two days before the end of DSV operations. As a result, the DSV's mooring locations were not digitally recorded after removal.

The umbilical for the ROV and all associated lines were floated to reduce the potential for damage to reef structures from dragging. However, initial attempts to float the ROV tethered at depth were inadequate. Once this was observed, it was rectified by changing out and adding flotation devices.

ARA was supported by subcontractors trained to address ROUMRS maintenance and unforeseen problems. These personnel had extensive experience working with ROV equipment and they were able to address readily maintenance issues with the ROV, the navigation system and the manipulators. Additionally, a local electrician made electrical repairs to the EHDS.

An exclusion zone of 500 feet was established and maintained around the RSV. This zone was required to eliminate the potential for fouling of lines, because the RSV's mooring lines and the ROUMRS' tether were buoyed and floating along the surface. These lines had the potential to be a navigational hazard, and if the lines were impacted by watercraft, damage to the ROUMRS system could have occurred.

4.1.3 Launch and Recovery of ROV

The ROV was launched and recovered from the RSV using an on-board crane and winch. The ROV umbilical was hand tended at all times during all field activities including during launch and recovery operations. This task required three men.

4.1.4 Placement of the Salvage Baskets

The salvage baskets were launched and lowered into the water from the DSV with the shipboard crane. A towboat then moved the baskets to their drop locations for lowering to the bottom using an on-board winch. Once lowered, the baskets remained in place until the ROUMRS operator attached a lift balloon that would lift it to the surface. Video taken by the ROV was used to survey and document staging areas before placement and after recovery of each salvage basket. In the first deployments of the salvage baskets, strong current caused the baskets to land wrong side up. As field activities progressed, toppled salvage baskets ceased to be a problem. Prior to retrieving UWMM, the ROV removed the salvage basket's surface down line, unlocked and opened the basket's door for receipt of recovered UWMM. All recovered UWMM fit through the salvage basket's doors.

4.1.5 Munitions Recovery and Sub-Sea Operations

During the Demonstration operational parameters were measured and recorded. Additionally, the ROV recorded 98 and 92 hours of video of the field activities on Channel 1 and Channel 2, respectively.

During field activities, the ROV was maneuvered to specific locations near the salvage baskets where it began to retrieve UWMM. The strength of currents at Ordnance Reef (HI-06) necessitated the ROV operate as close to a salvage baskets as possible. This reduced the ROV's time spent maneuvering UWMM to the salvage basket. The ROV was designed to place recovered munitions in its hopper for transport to the salvage basket. However, it was also capable of either carrying munitions that would not fit in the hopper to the salvage basket in its manipulators or attaching straps and a lift bag to such for direct lift and transport to the DSV.

During the Demonstration, 100-lb bombs, which were placed in the ROV hopper for transport to the salvage basket, were the largest UWMM recovered. Damage to the ROV hopper on the first day of field activities during which UWMM were recovered did not permit the hopper's mechanical transfer process to be used. Therefore, UWMM placed in the hopper were removed and placed in the salvage baskets using the ROV's manipulators.

The Demonstration team conducted reconnaissance with the ROV for a number of reasons. These included inspections and recording of mooring locations, verifying concentrations and distributions of UWMM relative to the RSV's mooring location, and locating, inspecting and recording the conditions of salvage basket staging areas. Equipment demonstrated during the reconnaissance included scanning SONAR, wide-angle and zooming cameras, pan and tilt camera mounts, underwater lighting, surface and subsurface navigation gear, which was used for planning and following the ROV's path, and topside data archiving hardware and software.

Prior to recovery, a UXO-qualified technician tentatively identified each munition recovered by category (i.e., UXO or DMM) and, to the extent possible, type, and size (e.g., 5 in, 105 mm). This identification was aided by the use of a laser scale and real time imagery. Additional activities included determining whether recovered munitions were fuzed, estimating the quantity and NEW, determining the distribution of UWMM in the immediate area, and estimating the time to fill a salvage baskets. The site condition and the condition of the UWWM, including those recovered, were digitally recorded prior to attempted recovery, after recovery and prior to movement. The pre-removal imagery allowed NOAA to assess any impact to corals.

When the ROV hopper was full, by either volume or weight, the ROV moved to the salvage basket where it emptied its hopper into the salvage basket using the manipulators. As this process proceeded, a running weight tally and tentative identification of munitions recovered was kept. Loose propellants and/or small amounts of raw explosives were not encountered; therefore, the suction pump was not tested on those materials. However, the Demonstration team tried the suction pump on SAA without success. This was expected given the shape of SAA. The Demonstration team used a scoop and bucket to recover SAA. (Section 5 provides the totals of munitions and other material recovered.)

4.1.6 Retrieval, Towing and Recovery of Salvage Baskets

When the salvage basket was full, the ROV attached a lifting bag to it. Once the ROV operator ensured that there were no surface craft above the basket, the ROV activated a compressed air tank to fill the lift bag in a controlled fashion. The system used was capable of lifting in excess of 2,000 lbs per salvage basket. The filled salvage basket rose to approximately 14 feet below the water's surface, which provided protection should an inadvertent detonation occur. Once at the surface, a small craft crew attached a towline to the lift bag's line and towed the salvage basket (as far as one mile) to the DSV for recovery and processing. A UXO-qualified Technician III or higher supervised the towing of the salvage baskets to the DSV where a qualified crane operator lifted the submerged basket onto the deck for subsequent processing of the recovered munitions in the EHDS (see below).

At the end of the Demonstration, all equipment and materials used were removed for disposition (e.g., shipment to the recyclers or equipment to the mainland). The RSV and DSV moorings and all equipment were removed, inventoried, and packed into shipping containers. The equipment was returned to the mainland without damage.

4.2 EHDS

The Army determined no single technology was available to demilitarize the variety of military munitions in diverse conditions (e.g., corroded, encrusted) potentially present in the underwater environment. For Ordnance Reef (HI-06), the Army required the treatment process not increase the explosive safety hazards to the public or personnel involved in the Demonstration and that the process be environmentally benign. As a result, the EHDS design used a combination of complimentary, proven, munitions demilitarization technologies. The EHDS is also considered suited for use in culturally and environmentally sensitive locations and locations where the NEW of munitions must be carefully managed.

The EHDS process involves remotely cutting recovered munitions and material containing MC using a wet-band saw, and then thermally treating the exposed explosive MC in the RCBOs. The EHDS consists of six RCBO housed in a standard 20-foot ISO container, power generators, an X-ray, a wet band saw, a munitions staging area, a crane, and other support equipment mounted aboard the DSV. Each of the six RCBOs can safely treat a NEW of approximately 20 pounds of explosive MC. The RCBO treatment cycle is between 1.5 and 2 hours.

The EHDS's band saw cuts munitions remotely to expose the explosive fill allowing for its thermal treatment in the RCBOs. The cutting of a munition also constitutes demilitarization. The cut munition pieces with the explosive fill exposed are placed in trays in the RCBO where the explosive fill is thermally treated until it nonexplosively decomposes, leaving a nonhazardous residue. After treatment, the metal scrap is inspected to ensure that residual explosive MC do not pose an explosive hazard (certified as MDAS) and is recycled.

Thermal treatment in the RCBO is not incineration, but rather what is termed "slow combustion." The thermal decomposition of explosives is an irreversible reaction that breaks the chemical bonds of the explosive MC. At no time do flames or the RCBO's radiant elements contact any of the exposed explosive filler. Thermal decomposition does not generate explosive gases. The EHDS design is intended to maintain temperatures well below the ignition temperature of the exposed explosive filler. Operators remotely monitor temperature of the RCBO in real-time to verify temperatures required for decomposition are reached and maintained and ensure temperatures that could cause a detonation are not reached.

With the exception of using an X-ray, the initial EHDS process steps are similar to the actions accomplished during a munitions response. The first step is to identify and inventory any munitions or MPPEH encountered. If the risk of moving a munition determined acceptable, it can be processed using EHDS. After being positively identified and inventoried, the second step is to segregate munitions by type and size. X-raying recovered munitions that have may not be able to be positively identified, whether due to age, rust, or the growth of marine life, helps ensure munitions that contain a liquid fill (e.g., white phosphorous, chemical agents) are not processed. This protects on-site personnel, the public, the environment, and equipment from injury, exposure, or damage. Step three is to place SAA, expended small arms cartridge casings, boosters, and fuzes directly into specially designed popping trays without remotely opening them. Loose propellants and other unconfined energetic compounds are placed in open trays. The next steps consist of remotely cutting and opening munitions and MDEH using a wet band saw. This operation safely exposes the previously confined energetic compounds, while the operators controlling the equipment work from a safe distance. Remotely cutting open munitions allows:

- Energetic MC to be sampled so the appropriate times and temperatures for treatment can be accurately determined
- Decomposition of the energetic MC to occur without the possible buildup of pressure that could cause an accidental mechanical detonation
- Operators to remotely cut the munitions into pieces reducing the net energetic contents to less than 20 pounds of NEW, which is the limit of the RCBO used to heat the energetic compounds
- Integrated base fuzes and boosters to be placed into the popping trays.

The treatment entails elevating the temperature of the RCBO to the level needed to irreversibly break the chemical and molecular bonds without reaching the ignition temperatures. The final step involves post treatment activities. After treatment, the temperature monitor logs are reviewed to ensure that the required temperature was reached, and an explosive safety officer visually inspects each RCBO tray to ensure no explosive hazards remain. If appropriate, the explosive safety officer documents the explosives safety status of the scrap metal as safe. If needed, material that poses an explosive hazard is retreated until the explosive hazards have been eliminated. The EHDS process does not use or generate hazardous wastes.

EHDS converts MPPEH to MDAS resulting in metals that can be released for unrestricted recycling. At the end of the Technology Demonstration, the equipment and residual materials were removed from Ordnance Reef (HI-06) for final disposition (e.g., recycling, redeployment to mainland).

4.3 Other Demonstration Activities

During the Demonstration, the Demonstration team supported, other studies and technology research of Army interest. These included testing of the Under Water Portable Acoustic Contraband Detector (UW-PACD) for the Navy’s SPAWAR, US Army Research, Development and Engineering Command (RDECOM)’s testing of Hammerhead, an underwater explosives detector, funded by DoD’s UXO Center of Excellence (UXOCOE), testing of an underwater survey camera developed by local high school students under UH's and Army's mentorship, and the Army, Navy and UH collaborative corrosion study. In addition to their stated objectives, these efforts tested the versatility and flexibility of ROUMRS, particularly the ROV.

4.3.1 UW-PACD

The UW-PACD demonstration effort focused on evaluating UW-PACD's ability to identify an UWMM's fill in situ using acoustic methods. UW-PACD technology is similar to medical ultrasound, and is the result of a recent Navy-led development effort (George, et al. 2008) for inspecting and classifying contents of containers in maritime environments both nondestructively and non-intrusively during security inspections. The specific technical objective for the Demonstration was to implement preliminary modifications of PACD for underwater applications and then demonstrate UW-PACD's capabilities. The long-term goal is to provide a validated screening tool for ascertaining integrity, fill level, and classifying content of munitions in the underwater environment.

UW-PACD measures the acoustic time-of-flight of a sound pulse that propagates through a bulk-solid or liquid inside a container (e.g., UWMM), and then computes the acoustic velocity of that material. This provides a unique non-destructive tool for evaluating the acoustic characteristics of the propagation medium. Material classification is based upon comparison with a database of known material behaviors and acoustic velocity profiles in the PACD software. The Army's interest in the UW-PACD was its potential capability to non-intrusively investigate the content of UWMM.

For UW-PACD's testing at Ordnance Reef (HI-06), two preliminary modifications were made to PACD unit. These were, (a) the existing transducer was replaced with a trigger-less transducer to avoid issues associated with the unit's triggering due to hydrostatic pressure at depth; and (b) the transducer communication cable was replaced with a much longer, low attenuation cable to accommodate the required shallow target depth for diver or ROV (2 to 50 m) without significant signal loss. Use of the longer cable also required some minor modification to the PACD signal acquisition electronics. For both diver and ROV employment, the remainder of the UW-PACD unit (power, electronics, data collection controller, and PDA and graphical user interface) resides topside, where the unit can be operated and triggered by support personnel.

UW-PACD testing at Ordnance Reef (HI-06) primarily demonstrated that the UW-PACD could acquire a signal through an UWMM with minimal effort. UW-PACD tests were performed on a 5-inch armor piercing munition at a depth of about 70 feet. The PACD interrogated several recovered munitions on the DSV's deck. During these interrogations the recovered munitions were kept in a tank of water pending interrogation. The UW-PACD employed a standard general use membrane during the field tests using the ROV. This membrane failed after this application. As a result of this failure, the UW-PACD unit was not used during interrogations on the DSV. Future efforts will employ a more rugged transducer membrane that is more suitable for interrogation of UWMM.

The 5-inch armor-piercing munition interrogated by the UW-PACD was classified as a World War II munition, likely containing Explosive D. Differences between the UW-PACD and the PACD in the measured acoustic velocities were determined to be caused by calibration issues related to UW-PACD modifications that were unresolved prior to the field demonstration. However, while the standard PACD result is considered more accurate, both results would indicate the round had likely breached, allowing seawater to seep into the UWMM. When the recovered munition was cut open for treatment, its fill was observed to be sludge. Explosive D, which is a compressed dry powder, is readily water soluble. When seawater seeps into an UWMM, the Explosive D degrades. Unlike the PACD's signal acquisition for UWMM 5-inch armor-piercing round, it is difficult for the PACD to acquire an acoustic signal on a dry compression-packed type of fill, as indicated by "no signal" in Table 4-1. The standard PACD unit also interrogated a recovered UWMM with a measured acoustic velocity of 2.46 +/- 0.18 km/sec. This acoustic velocity measured is in the range for TNT-based munitions that were filled using a melt-pour process. This munition was classified during the recovery and treatment process as a TNT-based high explosive round with a very dense fill.

Table 4-1: PACD Results

Munition Type	Fill Material	Reading in Tub Calibrated PACD	Reading with UW-PACD at a 21m depth
5-inch Armor Piercing	Wet Explosive D (breached)	1.32 +/- 0.50	1.10 +/- 0.46
5-inch High Explosive	TNT-based explosive	2.46 +/- 0.18	Not measured
5-inch Armor Piercing	Dry Explosive D (intact)	No signal	Not measured

4.3.2 Underwater In Situ Trace Explosives Detection (Hammerhead)

ROUMRS's ROV was used to deploy and test a new underwater sensor developed with funding from DoD's UXOCOE by RDECOM's Communications-Electronics Research, Development and Engineering Center's Night Vision and Electronic Sensors Directorate (NVESD). Dr. Marc Woodka, a chemist with NVESD, developed a sensor concept at the laboratory scale capable of detecting and discriminating between explosive compounds at concentrations down to 10-100 parts per trillion. Currently there are no commercial technologies available capable of detecting the trace quantities of explosives emanating from UWMM. In response to this need, NVESD packaged this bench-top experimental setup into a deployable sensor unit, nicknamed "Hammerhead," that is capable of operations at depths of up to 100 feet. The sensor discriminates between different compounds using a biologically inspired fluorescent polymer sensor array, and achieves the trace-level sensitivity using a novel pre-concentration scheme.

During the Demonstration, the ROV deployed Hammerhead to sample the water near UWMM. The ROV re-positioned UWMM adjacent to Hammerhead for sampling. Hammerhead sampled water near 12 different UWMM, but it did not detect explosives emanating from these UWMM. Hammerhead's non-detections were confirmed by the post-deployment laboratory analysis of a trap at the sensor's outlet that would have captured explosives sampled throughout the sensor during deployment. While explosives may have been present in the water, they did not appear to be present above sustained concentrations of 10 parts per trillion. This was likely due to the low solubility of explosives, like TNT, in water, the slow rate at which explosives partition into water, and the presence of ocean currents at Ordnance Reef (HI-06) that continually dilute the water.

4.3.3 Remote Survey Camera

The Demonstration team also supported UH and local high school students by deploying of an underwater, remote survey camera that the students designed. Using ROUMRS's ROV, the Demonstration team deployed and recovered the camera twice during the Demonstration and collected photographs of UWMM over extended periods. The camera, its supporting casing and stand were easily deployed and moved by the ROV. The camera's successful deployment proved the design worked, as intended. Over a 24-hour period, the camera captured pictures of sea life's reaction to or interaction with UWMM. The students subsequently published a technical paper on their work in the May/June 2012 issue of the Marine Technology Society Journal.

4.3.4 Corrosion Study

Little is understood about the corrosion of munitions, either in the subsurface or underwater. This lack of understanding impacts the ability to estimate the time it takes to either breach (i.e., form a pinhole) a munitions' casing and allow a release of explosive MC and/or deplete the explosive MC in a munition that is experiencing continued corrosion (dynamic MC release source term). Data about UWMM is needed for modeling their corrosion, making defensible decisions concerning risk and required actions, and validating regulatory requirements related to UWMM in a marine environment.

Metal corrosion begins from the moment metal contacts seawater and is quickest near the beginning of environmental exposure (Epstein, et al. 1973; Van Ham 2002). The reaction rate depends on the temperature, presence of oxygen, quality and type of metal, and water currents at a disposal site. Examination of sea-disposed munitions indicates that the metal is degraded by saltwater contact, but the environmental factors are a significant influence on the rate of corrosion (Van Ham 2002). To gather scientific information about corrosion of UWMM, metal from recovered munitions were retained for study following treatment.

The UWMM corrosion study's objective is to evaluate the corrosion of munitions recovered from underwater. This evaluation is needed to develop a scientific basis for predictive modeling of specific corrosion behaviors for various types of UWMM. During the Demonstration at Ordnance Reef (HI-06), corrosion of UWMM was found to be more extensive than expected. Once encrustation of coral and other organisms were removed, some munitions' bodies were found to be partially or completely deteriorated. UH, with input from SPAWAR's Systems Center (SPAWARSYSCEN), San Diego, CA, is conducting the bulk of the corrosion profiling to advance knowledge of the effects of the ocean environment on UWMM. However, samples are also being provided to other universities to expand this research.

Laboratory-based work is evaluating the corrosion products and calcareous deposits associated with recovered munitions. This evaluation will be performed using one or more analytical methods (e.g., energy dispersive x- ray analysis, x-ray diffraction, Fourier transform infrared spectroscopy, or Raman spectroscopy). Casing materials also will be identified along with a corrosion profile developed to estimate localized and average corrosion rates using compositional, metallographic, and morphological analysis.

Finally, normal and galvanic corrosion or metallic surrogates will be evaluated under one or more conditions. These conditions include artificial seawater (abiotic), natural seawater (biotic), and marine sediment (biotic and abiotic) collected from Ordnance Reef (HI-06), or from artificial sediment prepared to technical specifications of Ordnance Reef (HI-06) sediments. The study's goal is to better understand how corrosion affects munitions allowing the development of models for MC release rates, particularly for munitions fill.

5. PERFORMANCE ASSESSMENT

The Technology Demonstration at Ordnance Reef (HI-06) showed that the ROUMRS was capable of locating and recovering UWMM and EHDS was capable of destroying recovered munitions safely at sea in an environmentally benign manner. This section presents the Demonstration's results including its costs. A cost comparison is made between use of ROUMRS and UXO-qualified divers to recover UWMM.

- ROUMRS collected and transported munitions as large as 155 mm projectiles and 100-lb. bombs.

- ROUMRS was not able to recover UWMM encased by coral or cemented to the bottom without significant effort and possible injury to coral and other benthic habitats. However, ROUMRS's hydraulic capacity is sufficient to power commercially available tools that can be used to free such UWMM with minimal impact to the environment. (The Army does not view this as a technology or capabilities gap.)

- ROUMRS' ROV required three people to tend the tether and recover it. An automated winch and use of an A-frame during launch and recovery would reduce the needed manpower.

- The salvage basket design proved problematic, particularly in high currents. Some simple adjustments (e.g., reduction of height, redesign of doors, and addition of ballast for control of descent) would reduce the potential for inadvertent damage to coral and other benthic habitats by allowing greater control during delivery and positioning. Simple design changes would also quicken recovery operations.

- There were no explosive incidents, although some explosives material did flash (ignite) within the RCBO.

- Although successfully demonstrated, the RCBO must be redesigned to improve temperature control, including heat distribution; better protect wiring (the existing wiring scheme exposed electrical wires and circuits to high heat and moisture, which resulted in ground faults and electrical failures); and ensure performance at maximum NEW loads. Simplifying the temperature controls, increasing heat circulation within the oven to maintain an even heat distribution, and moving the electrical conduits to an area that is less exposed would improve the system's performance and reliability.

5.1. Demonstration Results

The work plan prescribed methods for validating ROUMRS's and EHDS's performance, determining if these systems met design criteria, and determining the root cause of deficiencies. By doing so, the operating characteristics of these systems were documented.

ROUMRS' effectiveness was compared with the effectiveness of using UXO-qualified divers to recover UWMM. This comparison evaluates ROUMRS on a dollar-for-dollar basis against standard approach (i.e., use of UXO-qualified dive teams) to recover UWMM and evaluates the use of EHDS to treat and dispose of recovered munitions, within the parameters for which the technologies were designed. Determining whether ROUMRS is as cost effective as believed when compared to standard approach to recovering UWMM was an important component of this Demonstration. This determination would be based on the quantity of UWMM ROUMRS recovered, comparison of daily operational costs against those of the standard approach to recovering UWMM, the overall safety of operations, and the system's reliability.

The Ordnance Reef (HI-06) Technology Demonstration confirmed that safe, effective and environmentally sound options are available for the remote recovery of UWMM and for the safe treatment of recovered munitions at sea. This Demonstration provided additional tools (e.g., band saws and RCBO) for DoD's use during munitions response and other actions on land. Using ROUMRS will allow divers to be taken out of the loop (Kekaula, 2011). (Tables 5-1 and Table 5-2 provide additional data concerning ROUMRS's operations, with Table 5-3 providing additional information concerning EHDS's operations.)

Table 5-1 presents the time expenditures during the ROUMRS field operations. Time spent is divided into several areas including safety briefs, travel times to and from the RSV, ROV search time on the bottom, time for ROV maintenance, and performance of other tasks (e.g., preparing filled salvage baskets lifting, videotaping staging areas and bottom conditions, and support of other studies). The time is shown in clock hours (Hr) and man hours (Mhr).

Figure 5-1 through Figure 5-7 show the locations of recovered munitions and the area ROUMRS surveyed during the demonstration.

Table 5-1: ROUMRS OPERATIONS ON-SITE TIME DISTRIBUTION

Date	Briefings	Travel	Search	Maintenance	Other	Total	Activity
11-Jul	2hr/12mhr	1hr/6mhr	0	3.0hr/9mhr	7hr/42mhr	13hr/69mhr	Set DSV Moorings
12-Jul	1hr/6mhr	1hr/6mhr	0	2.0hr/6mhr	9hr/54mhr	13hr/72mhr	Set DSV Moorings
13-Jul	0.5hr/3mhr	1hr/6mhr	2hr/12mhr	3.0hr/9mhr	6hr/36mhr	12.5hr/66mhr	Set RSV Moorings
14-Jul	0.5hr/3mhr	1hr/6mhr	8hr/48mhr	1.0hr/3mhr	1.5hr/9mhr	12hr/69mhr	Flip Basket, Collect UWMM
15-Jul	0.5hr/3mhr	1hr/6mhr	8.5hr/51mhr	1.0/hr3mhr	1hr/6mhr	12hr/69mhr	Basket Up, Collect UWMM
16-Jul	0.5hr/3mhr	1hr/6mhr	4hr/24mhrs	8hr/24mhr	0	13.5hr/57mhr	Collect UWMM, Arm Down
17-Jul	0.5hr/3mhr	1hr/6mhr	4hr/24mhr	4.5hr/13.5mhr	2hr/12mhr	12hr/58.5mhr	Collect UWMM, Reset Laser to 2", Raise Basket, Lines Foul Thrusters
18-Jul	0.5hr/3mhr	1hr/6mhr	5hr/30mhr	3hr/9mhr	2.5hr/15mhr	12hr/63mhr	Collect UWMM, Raise Basket, Replace Thruster
19-Jul	0.5hr/3mhr	1hr/6mhr	9.5hr/57mhr	1hr/3mhr	0	12hr/69mhr	Collect UWMM, Recovering Projectiles
20-Jul	0.5hr/3mhr	1hr/6mhr	9.5hr/57mhr	1hr/3mhr	1.5hr/9mhr	13.5hr/78mhr	Collect UWMM, Lift Basket Trouble with Manipulators
21-Jul	0.5hr/3mhr	1hr/6mhr	8hr/48mhr	1hr/3mhr	1.5hr/9mhr	12hr/69mhr	Begin recovering SAA
22-Jul	0.5hr/3mhr	1hr/6mhr	9.5hr/57mhr	1hr/3mhr	0	12hr/69mhr	Recover SAA and Projectiles
23-Jul	0.5hr/3mhr	1hr/6mhr	6hr/36mhr	2hr/6mhr	1hr/6mhr	10.5hr/57mhr	Thruster Fouled but OK, UH Camera Deployed, Basket Lifted

Date	Briefings	Travel	Search	Maintenance	Other	Total	Activity
24-Jul	0.5hr/3mhr	1hr/6mhr	8.5hr/51mhr	2hr/6mhr	0	12hr/66mhr	Adjusted Sensors
25-Jul	0.5hr/3mhr	1hr/6mhr	6.5hr/39mhr	1hr/3mhr	3hr/18mhr	12hr/69mhr	UH Camera Recovered, Basket Lifted
26-Jul	0.5hr/3mhr	1hr/6mhr	7hr/42mhr	1hr/3mhr	4hr/24mhr	13.5hr/78mhr	Basket Recovered
27-Jul	0.5hr/3mhr	1hr/6mhr	10hr/60mhr	1hr/3mhr	0	12.5hr/72mhr	Collect SAA
28-Jul	0.5hr/3mhr	1hr/6mhr	7.5hr/45	1hr/3mhr	1hr/6mhr	11hr/63mhr	Basket Recovered
29-Jul	0.5hr/3mhr	1hr/6mhr	6hr/36mhr	1hr/3mhr	1.5hr/9mhr	10hr/57mhr	UH Camera Redeployed
30-Jul	0.5hr/3mhr	1hr/6mhr	0	1hr/3mhr	3.5hr/21mhr	6hr/33mhr	Last Day of Operations, Recover RSV Anchors, UH Camera Recovered

Table 5-2 indicates the total clock hours and man hours spent on major tasks. Table 5-3 presents a summation of the hours on site during the Demonstration for tasks performed during the Demonstration and the time spent for recovering items from the bottom.

Table 5-2: ROUMRS Operations Statistics

Task Description	Quantity
Recovering UWMM*	119.5hr/717mhr
Maintenance	39.5hr/118.5mhr
Ancillary tasks (e.g., recovering baskets, setting cameras, searching for the Waianae sewer outfall to avoid damaging it during DSV mooring)	46hr/276mhr
Attempted recovery of munitions*	218 units
Suspect munitions recovered	80 each
Partial/non- munitions/coral recovered	6 each
Munitions recovered	74 each
SAA recovered	2,300 each

*Many UWMM that were cemented to the reef could not be recovered

Table 5-3 summarizes the recovered munitions processed the EHDS. Forms that ARA generated during DSV operations are provided in Appendix B. Appendix C contains the destruction certifications.

Table 5-3: Munitions Demilitarized by the EHDS

Item Descriptions	Quantity
100 lb. bombs	4
5-inch armor piercing rounds	49
5-inch high explosive (HE) rounds	7
5-inch illumination rounds	6
40 lb. fragmentation bombs	4
4-inch propellant cartridge	1
1.1-inch propellant casing	3
SAA	2300

5.2. Technology Advantages and Limitations

Table 5-4 compares ROUMRS' performance to the Performance Work Statement. The use of the ROUMRS provides advantages over the standard approach to recovering UWMM. These include, but are not limited to increased flexibility and bottom time, and improved safety. ROUMRS' use is comparable to the historical use of ROVs in petroleum industry. ROUMRS, like EHDS, is composed of off-the-shelf technologies. As demonstrated, these technologies are suitable for a variety of activities, including recovery of UWMM. The Demonstration showed that with some minor modifications and additional tools, which are readily available or easily developed, ROUMRS' capabilities for use in addressing UWMM would be significantly enhanced.

DoD's clarification of its policy with regard UWMM, which made decisions for addressing such munitions risk based, increases the probability that the Army and other Services may address additional locations where UWMM are present. As this Demonstration showed, using a combination of ROUMRS and EHDS reduces the potential impact to the environment both during recovery, by reducing reliance on detonation in place, and destruction, by significantly reducing, if not eliminating, hazardous wastes.

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Shipping	Be able to be shipped by commercial methods.	The system meets weight requirements of shippers and fits into a 20 foot ISO container box.	Actual Performance, the system was shipped in standard CONNEX containers	The requirement was met
Setup time	The time the ROUMRS takes to setup before recovering targets	The setup time is the time from when ROUMRS arrives onsite until it is ready for operation. This time includes warm up time for the ROV and generator, travel time to the bottom, the setup of the communications antenna, etc.	Site personnel were routinely able to begin daily operations within one hour of beginning pre-dive tests.	Setup time defined during Technology Demonstration
Support Vessel	The ROUMRS can operate from a 55 ft to 75 ft (or smaller) vessel of opportunity.	Visual confirmation with realtime measurement.	Actual Performance. The support vessel was 74 feet in length. Using smaller support vessels is possible.	Proven during Technology Demonstration
Launch and Recovery Equipment	The ROUMRS can operate from a generic vessel that is capable of carrying the ROV and support equipment plus the recommended factor of safety as defined by the American Bureau of Shiping (ABS).	Visual confirmation along with weights from equipment specification sheets and or real-time measurements, in a recorded format.	Actual Performance, the ROV was launched from a vessel of opportunity with the ship equipped crane.	Proven during Technology Demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Recovery capabilities	Small arms ammunition, loose propellant, munitions having lost structural integrity. Must be able to contain bulk energetic materials.	Suction pump must be capable of recovering bulk energetic and loose propellant. Openings in the salvage basket must be small enough to prevent the escape of loose large caliber ammunition propellant.	No loose propellant was observed during the demonstration. Was not able to collect SAA with pump	Not able to test during Demonstration
Targets per day	The number of targets that the ROUMRS can clear per day	This is determined by counting the number of targets the ROUMRS is able to collect from the bottom and place in the salvage basket in a given time period.	2300 SAA were collected. The daily maximum rate was not tested. The maximum number of medium or large projectiles was 29 objects.	29 larger items in a 12 hour day and thousands of SAA items could be collected.
Lifting capacity of manipulators	150 lb. projectile shape, 155 mm projectile	Review of design and confirmation by a knowledgeable person with scaled loads for confirmation, if possible.	Actual Performance showed that the manipulators were capable of picking up 155 mm projectiles.	Proven. 100 lb bombs were the largest item lifted by manipulators (aproximately 8 inches in diameter).

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Sonar	High resolution scanning for bottom navigation and target location	Review of design and confirmation of system equipment by a knowledgeable person.	Actual Performance, the sonar was used to navigate and locate objects on the bottom that were beyond visual observation distances.	Proven during Technology Demonstration
Photo/video equipment	Low light camera for navigation, high resolution camera for work area documentation, camera on manipulator, auxiliary camera, digital stills from a dedicated camera or high resolution video frame	Review of design and confirmation of system equipment by a knowledgeable person	Actual Performance, the cameras captured numerous still photos as well as hours of video.	Proven during Technology Demonstration. No night work was performed to test in low light conditions.
Recording	Video, sonar, digital stills must be recorded on digital media and stamped with date/time and geo-referenced position	Review of design and confirmation by a knowledgeable person.	After some initial issues with placing geo-referencing information onto the video, this information was placed onto the video and the still photographs.	Proven during the Demonstration.
Measuring	Laser scaling system to aid in identification of munitions in situ	Visual confirmation by a knowledgable person.	Actual Performance	Proven during Technology Demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Crew size	Maximum of 4 per 12 hour shift, or 7 for 24 hour operations (does not include personnel for vessel operations)	Review of design and confirmation by a knowledgeable person. All measurements will be recorded during a three week operational window.	Due to strong currents, the crew size was six	5 personnel are the optimum crew. A powered spool for the tether would allow operation of the system with 4 personnel.
Endurance	Capable of working a minimum of 160 continuous hours in the water between recoveries	Confirmation of demonstration operations by a knowledgeable person.	The system worked for 21 straight days without going back to port for maintenance, but the system was recovered daily	Not fully tested during the technology demonstration.
Vehicle lift capability	Up to 130 lbs dynamic lift using onboard thrusters	Review of design and confirmation by a knowledgeable person with scaled loads for confirmation, if possible.	Lifted approximately 300 lbs with 4 UWMM items (2 – 100lb bombs and 2 – 5" projectiles) in the Hopper	Proven during Technology Demonstration
Lifting basket/bag capability	Capable of lifting up to 2,000 lb from a depth of 200 feet	Review of design and confirmation by a knowledgeable person with scaled loads for confirmation, if possible.	Lifted a salvage basket with 29 assorted UWMM items.	Proven during Technology Demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Containment	Lift basket/bag must be provisioned to allow containment of propellant grains, bulk explosives and munitions debris while allowing fine sand and water to pass through	Design specification, inspection of equipment following use and during field demonstration.	Review of design and confirmation by a knowledgeable person	Fine sand and water easily passed through the basket. Loose bulk explosives and propellants were not encountered during the demonstration.
Distance from munitions to detonation or transfer to alternate transport	Lift basket will be designed to be towed up to one km at sea state 3 or less by small craft and sturdy enough to be lifted from the water by a	Review of design and confirmation by a knowledgeable person in the field.	Actual Performance	Baskets were towed successfully but distances and sea conditions were not exceeded
Navigation	Within 2.5 meters topside and 5 meters underwater	Review of design and confirmation by a knowledgeable person in the field.	Actual performance	Proven during Technology Demonstration
Munitions Assessment	Capable of supplying sufficient data in real-time to allow a UXO qualified person to identify the munitions by family (e.g. 155 mm, 100 (lb) pound bomb), type (high explosive) and category (i.e., as UXO, DMM	The log and digital record will be checked against the munitions brought to the demilitarization barge where the comparison will be made at the unloading of the salvage basket.	Actual performance	Proven during Technology Demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Quantity of material removed	Pounds of scrap	Weight of all items removed (both DMM and scrap) is weighed to calculate nominal weight per day removal rate	Approximately 1000lbs of Munitions Debris and 300 lbs of small arms scrap	Full capacity was not tested during the demonstration
Bottom clearance rate	Square yards per day that the ROUMRS can recover munitions (e.g. DMM)	This criterion is determined by picking up surface munitions (e.g. DMM) for a specified time period (4 hours, for example) and determining what area was covered during the time period. This result can then be extrapolated to an 8 hour day.	Not Tested. Many munitions were encrusted and cemented to the bottom.	Not proven or tested
Percentage (%) - object (target) recovery	The percent of MEC objects recovered within the ROUMRS design parameters	This parameter measures the number of targets removed from the bottom vs. the number of targets present in the bottom. Targets are those items that are detected by a camera operated by a trained individual	218 items surveyed or attempted to recover with 80 items recovered	Proven during demonstration to be 37% in areas searched.

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Factors affecting technology performance	Weather	This criterion is evaluated by documenting the actual field conditions when ROUMRS was able to launch and operate in the presence of precipitation, wind, and a sea state of 3 etc. Although these factors cannot be predicted or planned, when they do occur, the ability of the ROUMRS to operate as intended is determined.	The weather at the demonstration site did not approach sea state 3	ROUMRS proven to be effective in ideal conditions.
	Temperature	The ROUMRS should not be affected by either very low or very high temperatures -2C to 32C seawater and -20C to 43C air. The water and air temperatures are recorded daily on the days the ROUMRS is operated.	Temperatures at the site were not extreme (26C to 32C in air and approximately 25C in water)and not tested.	Not proven during the demonstration

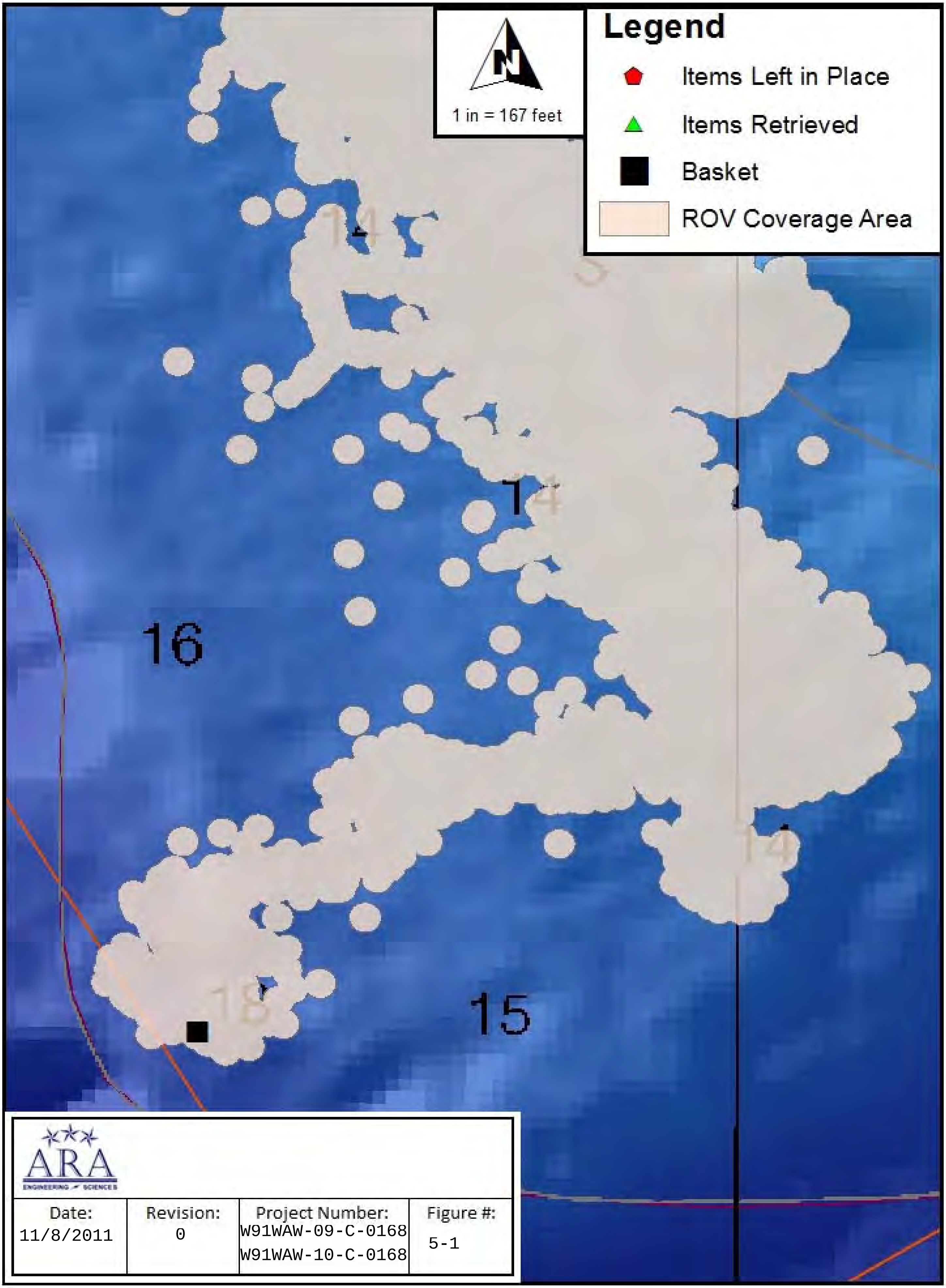
TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
	Bottom Conditions	The ability of the ROUMRS to meet the recovery parameters at depths of 20 to 300 ft (120 ft for the demonstration) and adaptable to 1000 ft. In addition, the ability of the ROUMRS to navigate in 2 knot currents without and 1.5 knots with the ROV hopper is equally important. This will be determined to the extent possible by measuring site conditions during the demonstration.	ROUMRS operated at depths up to 130 feet and peak tide currents are estimated to have exceeded 1.5 knots with the hopper attached	Proven during Technology Demonstration
Reliability	Was the system dependable each time it was called upon to operate?	Reliability is determined by recording the number of failures over the hours which the ROUMRS is operated to determine the Mean Time Between Failure (MTBF)	Other than start up problems and breakage caused by operator error as with the fouled thrusters the system proved to be reliable. MTBF caused by all factors was approximately 67 hours.	Proven during Technology Demonstration
Ease of use	Could a person who was trained to operate similar ROV equipment operate the ROUMRS equipped craft?	This criterion is evaluated by instructing individuals with and without heavy equipment training in the operation of the ROUMRS and evaluating their performance.	Operation of the manipulators and drive systems was performed by people with minimal training. Maintenance of the system requires training and experience.	Proven during Technology Demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Versatility	Was the ROUMRS ROV capable of doing more than one related job during the MEC removal? Could it operate on different bottom terrains?	This parameter is evaluated by operating the ROUMRS on different bottom terrains and noting any difficulties in operation.	The ROV performed well in various currents, on sandy, rock, and coral bottoms. The ROV performed various scientific sensor deployments along with recovery of UWMM	Proven during Technology Demonstration
Maintenance	Did the maintenance requirements for the ROUMRS limit the field operations?	A total of 39.5 hours of maintenance was performed during the demonstration to repair equipment that limited field operations	The manipulators required maintenance due to water intrusion in the system (1.5 hrs). One thruster was replaced due to damage from fowling (4.5 hrs).	Proven during Technology Demonstration
Depth of target extraction	Maximum depth into the sediment at which targets can be extracted from the site	This criterion is determined by measuring to the bottom of holes left in the sediment resulting from target extraction. With the aid of attachments, the ROUMRS is expected to reach targets at 6".	SAA was removed from sands to a depth of approximately 6 to 12 inches using a scooping tool	Proven during the Demonstration
Maximum reach of the manipulators	Maximum reach without compromising stability with various loads	This is determined empirically by extending the ROUMRS tether within the safety recommendations of the operator.	ROUMRS manipulators had a reach of approximately 1 meter	Proben during demonstration

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Reliability of the ROV	Mean Time Before Failure (MTBF)	This criterion is determined by dividing the number of failures of the ROV/operating time. Routine maintenance items are not considered failures.	Actual Performance	67 hours MTBF
Time required to repair the ROV	Total labor hours required, including actual repair time plus the time to obtain spare parts	This criterion is evaluated for the live demonstration. Each repair operation of the system is documented and the time to repair is recorded	Actual Performance	39.5 hours of maintenance was performed
Time required to repair recovery/lift system	Total labor hours required, including actual repair time plus the time to obtain spare parts	This criterion is evaluated for both the live demonstration and the tank test/shakedown. Each repair operation of the ROUMRS is documented and the time to repair is recorded.	Actual Performance	Although there was a bad manifold supplied by the manufacturer. There was no time loss for the recovery system.
Dimensional size of target removed	Maximum 150 lb from the bottom down to 6 inches with use of the manipulators	Observation by a knowledgeable person in the field.	Actual Performance	100 pound bombs and 5inch projectiles were recovered (8inch diameter 100lbs)
Maneuvering at the live site	Ability to navigate through various bottom conditions at up to Sea Condition 3	Observation by a knowledgeable person in the field.	Actual Observations	Full moon tides were encountered during the Demonstration and the ROV maneuvered well. Care had to be taken with baskets in strong currents

TABLE 5-4: PERFORMANCE CONFIRMATION CHECKLIST				
Performance Criteria	**Description**	**Performance Confirmation Method**	**Actual Performance / Post Operation**	**Comments -Add extra sheets as necessary**
Maintenance	Maintenance requirements for the ROUMRS do not limit field operations	Document the maintenance required during the demonstration	Actual Performance	Approximately 1.5 hours of maintenance was required per day to maintain and test ROV systems
Scalability	Able to put a ROUMRS-equipped ROV onto other applicable MEC remediation sites	Use of other robotic platforms of various sizes	Actual Performance	The ROV carried several other items to the seafloor, including a SPAWAR Sensor, an explosive detection sensor and UH's underwater camera

Basket 1 Items



Basket 2 Items

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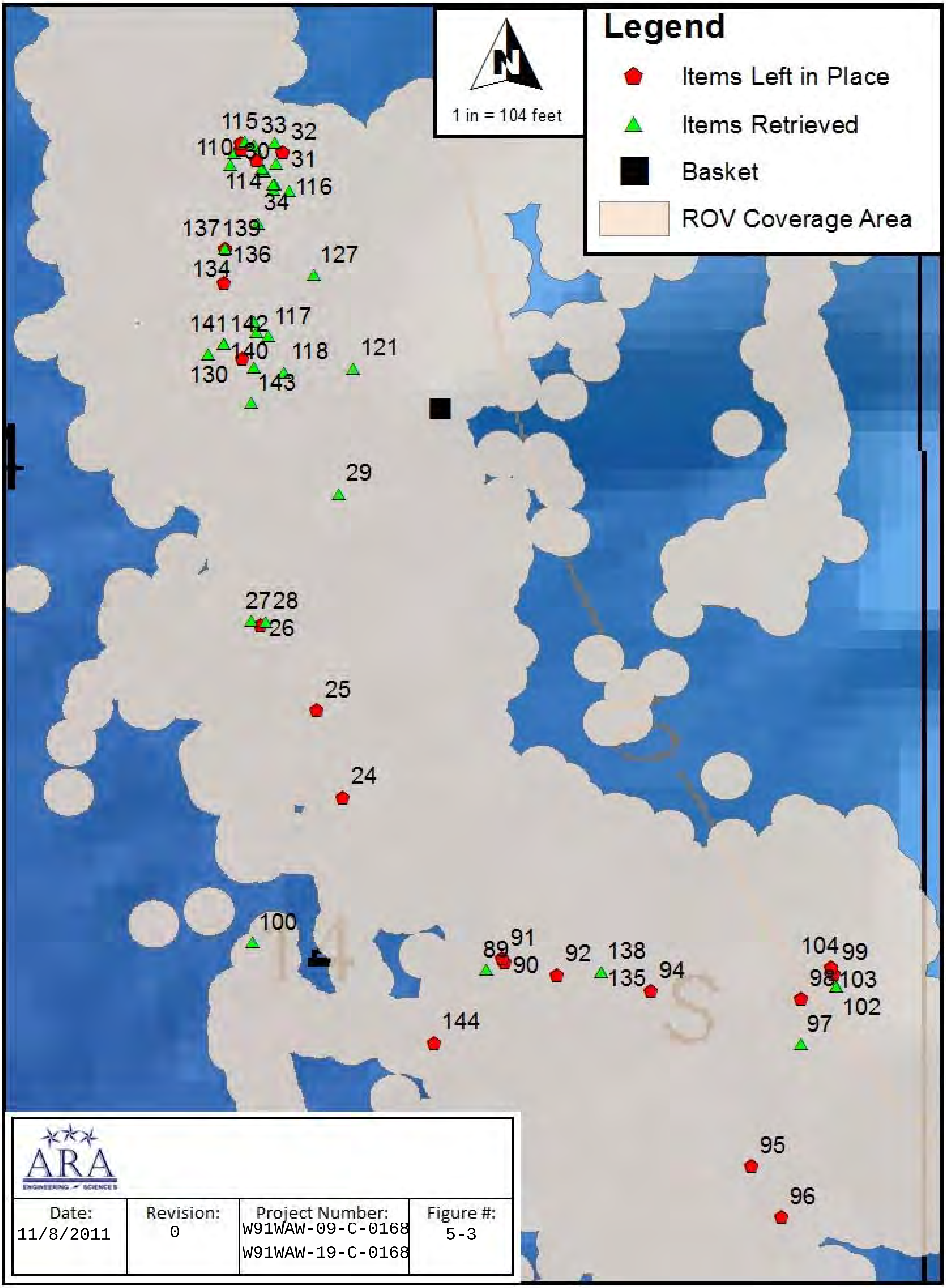
Basket 3 Items



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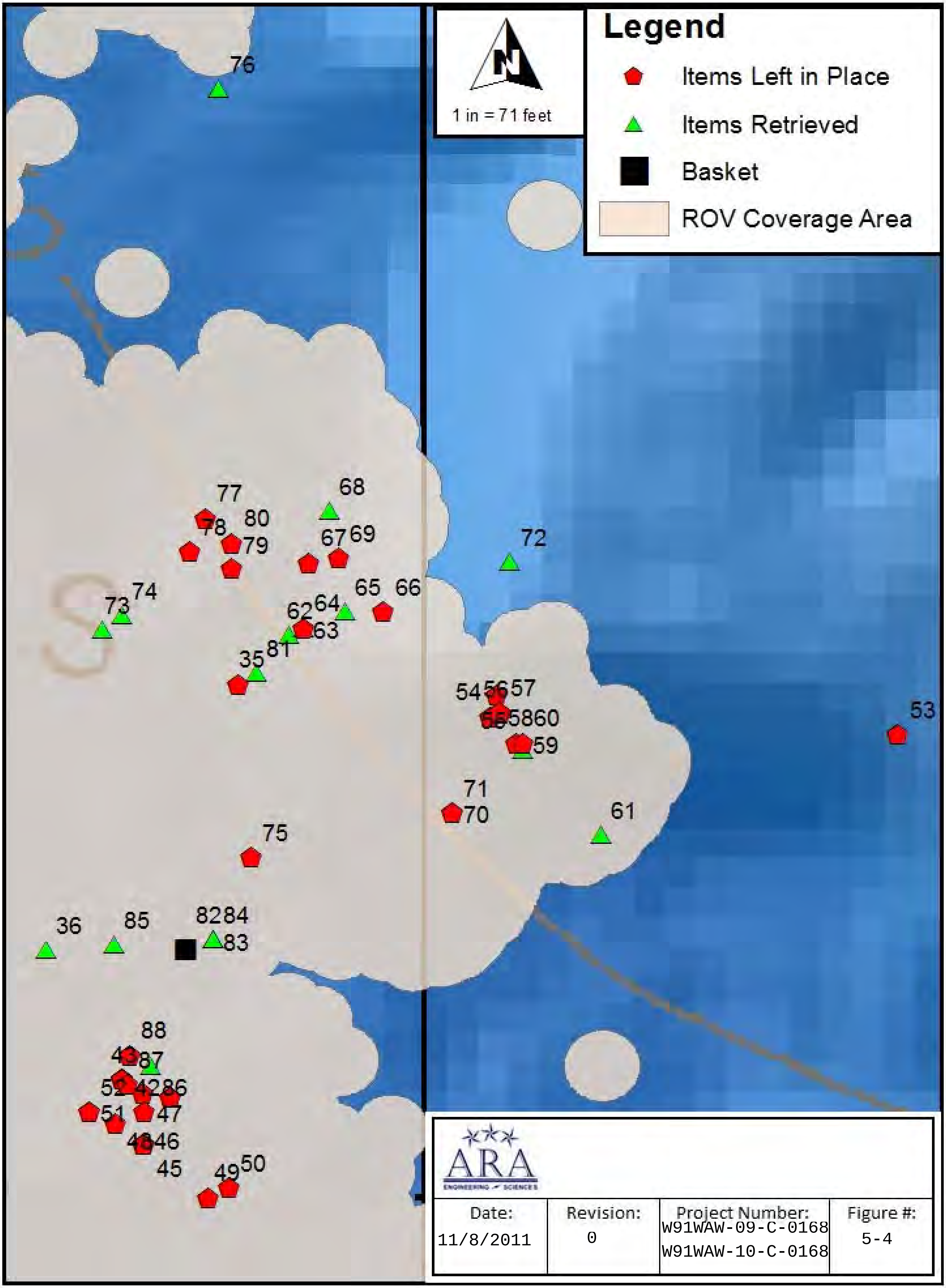

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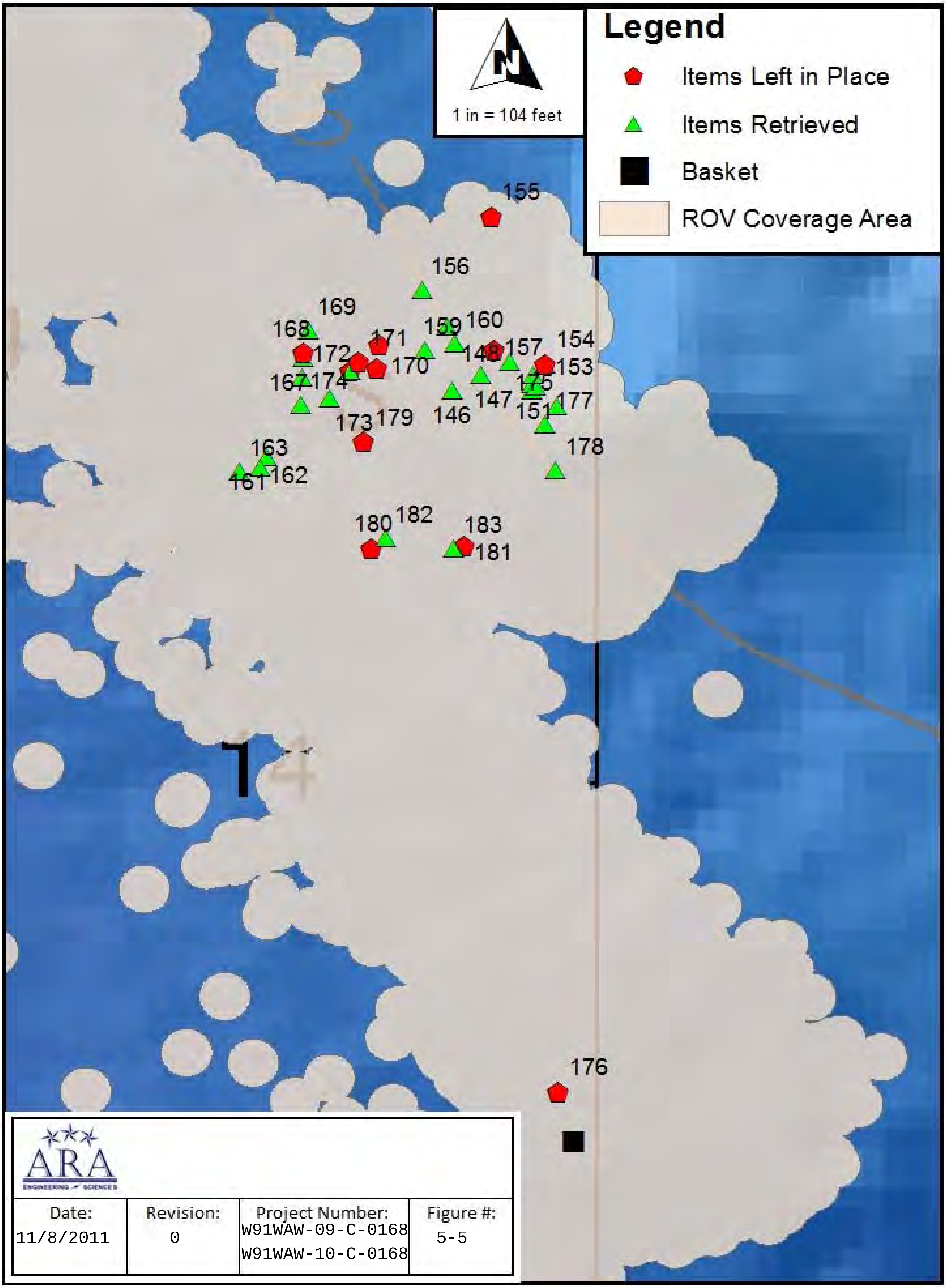

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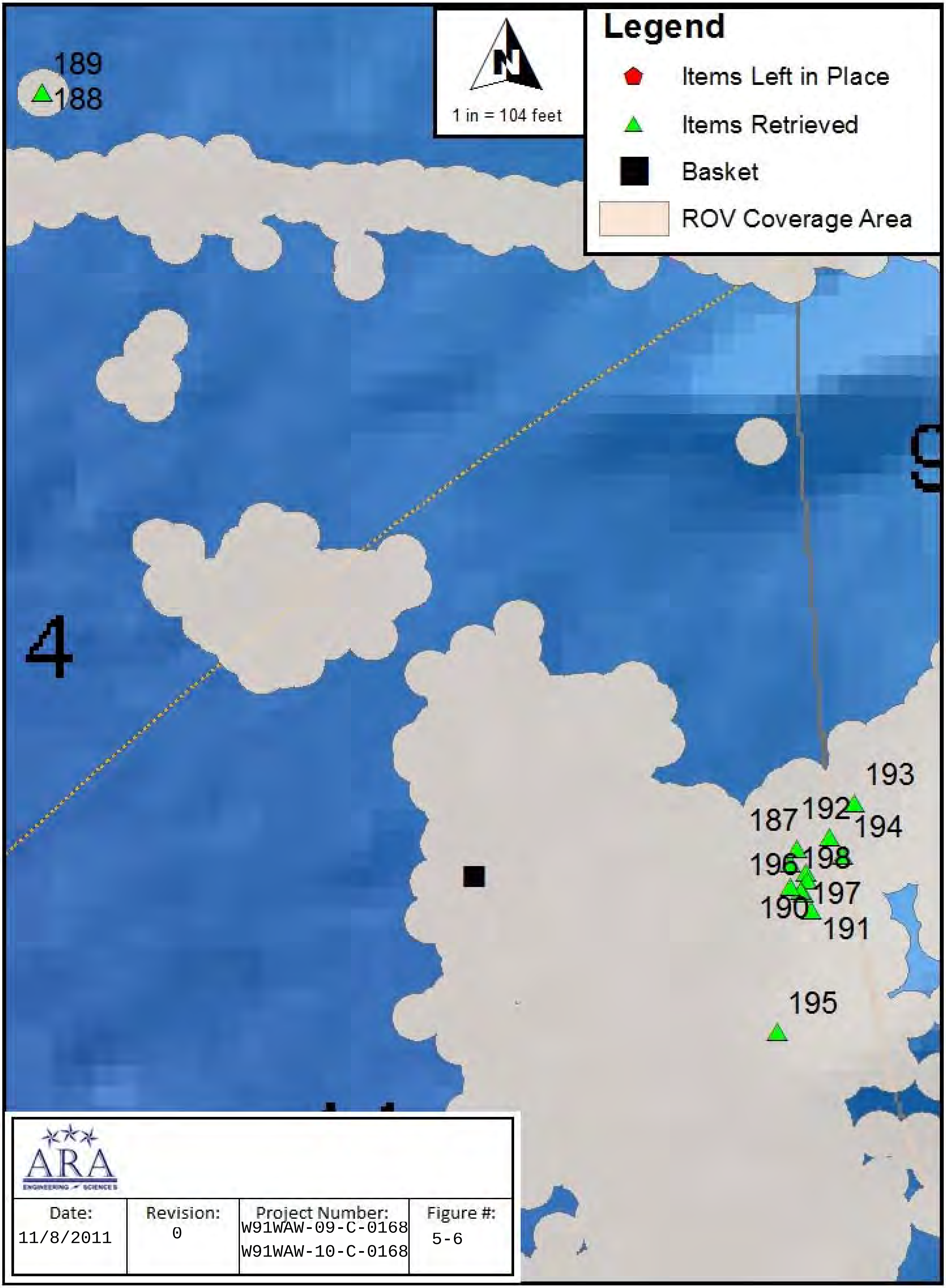

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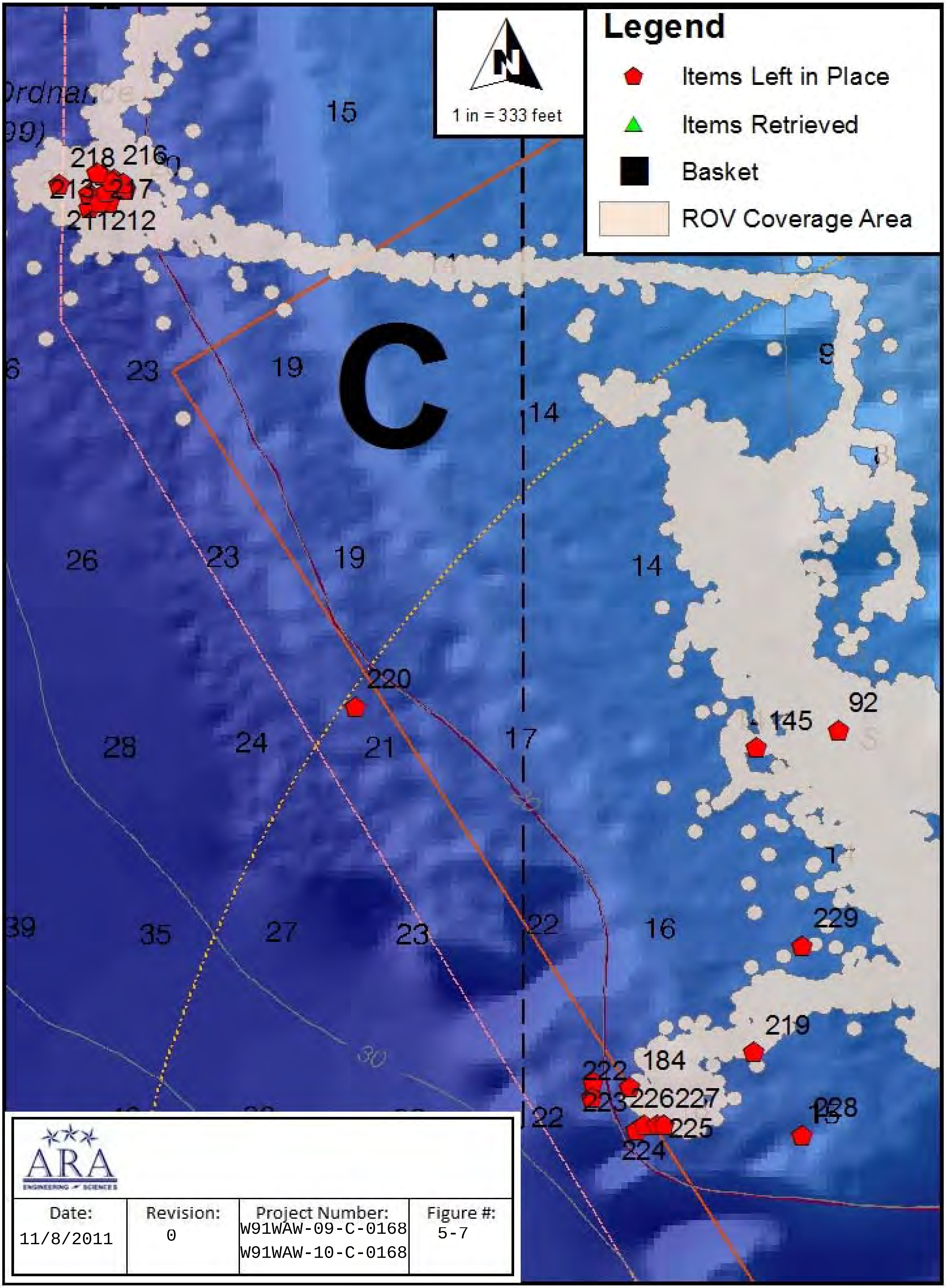
Other Items Identified



6. ROUMRS COST ASSESSMENT

The incurred costs to field the ROUMRS and EHDS during the Ordnance Reef (HI-06) Technology Demonstration are presented in Table 6-1. A total of 62 projectiles, 8 bombs, 4 propellant cartridges, 2300 rounds of SAA, and several pieces of scrap were collected by ROUMRS. The munitions collected were destroyed by the EHDS. A total of 25 days were spent in the field (July 11 through August 4). ROUMRS operated for 21 days and the EHDS operated for 25 days during the demonstration. In the future, these costs could be much lower, assuming that two 12-hour shifts allow for 24 hour operations, and in areas where pleasure craft are not as numerous. These costs were also used to develop projections for monthly operations. This breakdown shows some of the differences that can be expected when using the standard approach to recovering UWMM, but costs per item were not compared since the productivity observed while using UXO divers varies widely based on site specific conditions such as depth, water temperature, sea states and visibility.

6.1. Cost Model

Table 6-1 provides the actual cost incurred during the Demonstration for each element. From these costs, a simple cost model for ROUMRS and EHDS that reflects the primary costs for using these technologies at a site was developed. During the Demonstration, ARA tracked data for each cost element, with exception of those supplied by sub-contractors. For those elements supplied by subcontractors, the subcontracting cost is listed. Table 6-2 provides the cost elements. The cost associated with using ROUMRS to recover UWMM and to dispose of recovered munitions using the EHDS consist of:

- Transport of the ROUMRS and EHDS to Hawaii and Ordnance Reef (HI-06)
- Setup of the ROUMRS and EHDS (unpack the shipping containers, test system)
- Labor (staff for 30 days and a work schedule of 12 hour and 24 hour per day). This includes periods of inactivity because ROUMRS and/or EHDS could not be operated. Such periods are believed representative of delays that could typically be expected during any operation. (See Table 5-1.)
- Calculated total cost of operation for ROUMRS for a work schedule of 12 hour and 24 hour per day

Table 6-1: Actual Costs

Cost Element	Data Tracked During Demonstration	Costs	Daily Cost
ROUMRS System Capital Cost	Component costs and integration costs • Sub-Atlantic Comanche ROV • OII Hopper & ROV Modifications • Salvage Baskets and Lift Balloons • Kraft Manipulators • Underwater Lights • Cameras • SONAR/USBL Navigation • Archiving Software	$1,011,000	NA
ROUMRS Mobilization and Demobilization	• Cost to mobilize/demobilize ROUMRS to site, including setup and ship load out	$123,000	NA
ROUMRS Operational Cost for 21 days 12 Hr Day	• Includes RSV, the *Huki Pau* ($95,000) • Includes staff and per diem during the 21 days to operate ROUMRS	$551,000	$26,238
EHDS Capital Costs	• EHDS Hardware • EHDS Controls • EHDS Miscellaneous	$707,000	NA
EHDS Mobilization and Demobilization	• Cost to mobilize/Demobilize EHDS to site, including setup and ship load out	$168,000	NA
EHDS Operational Cost 12 Hr Day	• Includes DSV ($105,000) • Includes staff to operate EHDS	$1,163,000	55,380

Because inclusion of the capital costs in this estimate (for the Demonstration) skew the cost to appear more expensive, the capital costs should be amortized over the life of both ROUMRS and EHDS. However, Table 6-2 includes the capital cost for (a) ROUMRS, including the ROV, miscellaneous equipment and any attachments; and (b) EHDS, including the RCBOs, controls and shipping containers, and other associated equipment. These costs are shown in the following table. The cost of a command center structure is not included because such a center would also be required for manual excavation activities.

Table 6-2: ROUMRS and EHDS Capital Costs

Capital Equipment	Cost
ROUMRS	
Base ROV	$620,000
Manipulators	$189,000
Tether and Latch	$31,000
Cameras and Sensors	$25,000
ROV Miscellaneous Hardware	$76,000
ROV Modifications and Software	$70,000
Total	**$1,011,000**
Capital-cost amortized over 10 years	**$101,100**
EHDS	
EHDS Hardware	$369,000
EHDS Controls	$275,000
EHDS Miscellaneous Hardware	$63,000
Total	**$707,000**
Capital-costs amortized over 10 years	**$70,700**

Although ROUMRS and EDHS only operated 12 hours per day during the Demonstration, both were capable of 24-hour per day operations. If operated 24 per day, efficiency would be significantly increased. As an example, on-bottom time for collection of UWMM would double given that the ROV would only need to be launched and recovered once within 24 hours, and only one of two shifts would be required to perform maintenance. A significant part of the cost of any operation is the vessels. By conducting operations 24-hours per day, vessel costs would be cut in half which would significantly reduce total project costs. The ROUMRS ROV effective life is approximately 10 years.

ROUMRS operated underwater for 119.5 hours, addressing 11 acres at a rate of approximately 0.1 acres/hour.

For modeling costs, a hypothetical job requiring 360 hours of bottom time at 70 feet was analyzed. The costs associated with the Demonstration can be compared to an equivalent 360-hour (bottom time) operation using dive teams. These calculations are based on the assumption that four, two-man dive teams would operate 10-hour days (resulting in 5 hours of bottom time per day or about 40 minutes of bottom time per diver per day), working a standard 50-hour work week for a total of about 14 weeks. These calculations considered support personnel requirements for either approach equal. Table 6-3 indicates the relevant costs that would be incurred using a standard approach to recovering UWMM to allow comparison of similar data collected for ROUMRS during the Demonstration.

Table 6-3: Cost Model Using Standard Approach

Cost Element	Description	Estimated Costs for 360 Hour Bottom Time Operation	Weekly Cost	Cost per Hour of Bottom Time
Capital Cost	Dive Equipment (ODCs)*	$26,000	NA	NA
Mobilization and Demobilization	Mobilization of personnel, shipment of equipment and ship time, and setup	$118,000	NA	NA
Diving Recovery of UWMM Labor Cost for 101 days	Total labor costs based on a 10 hr day, allowing for 360 hrs bottom time, as with ROUMRS	$623,00	$43,000	$1,700
Diving Recovery of UWMM ODC Costs for 101 days	ODCs including a vessel with Surface supplied air, per diem, trucks, etc	$1,057,000	$73,000	$3,000
Diving Recovery of UWMM Total Operational Costs for 101days	Combined cost for labor and ODCs for the field effort to recover UWMM using standard approach	$1,825,000	$126,000	$5,100

Note: Assumes total duration of field effort is 101 days, with onsite work five days per week.
*Assumes surface supplied air, without a requirement for an on-site decompression chamber

6.2. Cost Benefit

The cost of recovering UWMM using the ROUMRS has been compared against the baseline for the standard approach for recovering UWMM. The cost model for ROUMRS and the standard approach for recovering UWMM includes the below assumptions:

- An equivalent bottom time of 360 hours.
- The effectiveness of either approach is a variable based on team composition; therefore, it is not examined.
- Both approaches would use support equipment of equivalent costs.
- Teams supporting both approaches spend two hours per day travelling to and from the shore and servicing equipment.
- The depth of water is at least 70 feet.
- ROUMRS' team is composed of five on the boat and an onshore manager.

- The dive team is composed of eight persons on the boat and an onshore manager. Dive labor based on Service Contract Rates for Hawaii.
- The dive team, using four rotating teams of two works 10-hour days, 5-day per week, and is able to spending five hours on the bottom per day. (Bottom times decreases drastically as the depth increases.)
- ROUMRS team is capable of working 12-hour days or, if augmented with an additional crew of five, 24 hour days, with 12-hour shifts. ROUMRS bottom times are assumed to be 10 hours per shift. ROUMRS labor based on actual ARA labor rates.
- The ROUMRS team takes one day off per week, while the dive team requires two days off per week for recuperation.

Based on the above assumptions, ROUMRS is capable of achieving 360 hours of bottom time in 36 work days or 41 calendar days (for 12-hour operations), while the dive team requires 72 work days or 101 calendar days (for 10 hour operations).

Using these assumptions the total operational cost for achieving 360 hours of bottom time is as follows:

- **The cost for ROUMRS is approximately $1,269,500** operating on a 12-hour schedule for 41 Calendar days, including labor, ODCs, and mobilization. $1,299,860 ≈ [(41 x $26,238) + 123,000 + 101,100].
- **The cost for a UXO qualified dive team is approximately $1,943,000** including 101 calendar days, ODCs, and mobilization. $1,943,000 ≈ [(101 x $18,066) + 118,400]

This cost model indicates that an approach using **ROUMRS on a 12 hour day schedule is approximately 33% less than the cost of using a UXO qualified dive team** for the recovery of UWMM.

ROUMRS is capable of operating 24-hours per day with the addition of 5 crew members. Assuming the same efficiencies and production rates, 24 hour operations would achieve 360 hours of bottom time in 18 work days or 21 calendar days. Table 6-4 shows the costs of the additional labor and perdiem required to perform 24 hour operations for 21 days.

Table 6-4 Additional Costs for 24 hour operations

Item	Avg Rate	Hours	Days	Amount	Weeks	Total
ROUMRS Staff	$130	12	6	5	3	$140,400
Flights	$1,370	1	1	5	1	$6,850
Perdiem	$293	1	7	5	3	$30,765
					TOTAL	$178,015

Table 6-5 presents the associated costs for 24 hour operations for 21 days. 360 hours of bottom time are achieved by 6 day/weeks with 20 hour of bottom time per day for 3 weeks. The cost model shows that operating **ROUMRS on a 24-hour day schedule is approximately 25% less than the cost of 12-hour day ROUMRS operations**.

TABLE 6-5: Associated Costs for ROUMRS 24 Hr shifts

Cost Element	Description	Estimated Costs for 360 Hour Bottom Time Operation	Weekly Cost	Cost per Hour of Bottom Time
ROUMRS Mobilization and Demobilization	Cost to mobilize/demobilize ROUMRS to site, including setup and ship load out	$123,000	NA	NA
ROUMRS Capital Costs	Costs Amortized over 10 years	101,100	NA	NA
ROUMRS Operational Cost for 21 days	• Includes RSV, the *Huki Pau* ($95,000) • Includes staff and per diem during the 21 days to operate ROUMRS during the demonstration	$551,000	NA	NA
ROUMRS Recovery of UWMM Labor Cost for an additional 12 Hr per day during 21 day effort	Additional labor, ODCs, and per diem costs based on a 24 hr day for 21 days	$178,000	NA	NA
ROUMRS Recovery of UWMM Total Operational Costs for 21 - 24 hour days	Combined cost for labor and ODCs for the field effort to recover UWMM using ROUMRS	$953,100	$317,700	$2,650

Army concerns about public safety and the potential impact to the environment (e.g., marine life) eliminated the use of blow in place operations, with exception of explosives or munitions emergencies. Although the Army considered transporting recovered munitions to an established underwater EOD range for destruction underwater, it ruled this approach out because of both costs and safety issues. The Army determined that transport to an Army operational range for open detonation would both be costly and increase the potential risks to the public. Therefore, the operational costs provided in Table 6-1 include 7 days of standby time, while EHDS awaited receipt of the initial salvage baskets of recovered munitions (approximately $387,660 of standby costs). For these reasons, comparison of the costs of the EHDS to the costs of open detonation is not practical. The use of blow in place or open detonation to destroy recovered munitions is less expensive than the use of technologies, like the EHDS. However, the use of open detonation as a means of addressing recovered munitions presents some challenges, particularly when the site of recovery is located in populated or high use areas. Table 6-6 presents the costs of treatment and disposal using EHDS on a per round basis during the Demonstration. SAA was only disposed of on weekends (4 of 21 days) and recovered munitions were disposed of during the week (11 of 21 days).

Table 6-6: EHDS Costs per Round

Method	Crew Size	Total Destroyed	Total Days	Hours / day	Man Hours	Avg Labor $/hr	Labor	ODC	Total	Cost per round
Recovered MM	4	74	11	8	352	$156	$54,912	$450,000	$504,912	$6,823
Recovered SAA	4	2300	4	6	96	$156	$14,975	$257,000	$271,975	$118
Total Effort	4	2374	15	8	448	$156	$69,888	$707,000	$776,887	Not relevant

7. LESSONS LEARNED

Demonstration team members were asked to address issues that affected activities for which they were responsible during the Technology Demonstration. Each section addresses specific tasks performed and suggested solutions to the issues identified.

7.1. General Comments

In general the system performed very well with little downtime. Maintenance times could have been drastically reduced with additional spare parts. Although spares such as a spare manipulator, compensators, and cameras are expensive, having these additional spare parts and electrical components would reduce down time for both the ROV and the EHDS system. Damaged parts could be replaced with functioning spares and repair to damaged parts could occur during operations instead of while operations were stopped.

7.1.1. Breaking UWMM Free from the Bottom

Many munitions on hard bottom were firmly cemented in place. The ROUMRS manipulators and tooling available or fabricated (e.g., pry bars, modified shovels) were largely ineffective in breaking such munitions loose in a short amount of time (5 minutes or less) or without damage to surrounding coral or benthic habitats. Although bumping concreted munitions with the 2,000-lb ROV's skids worked, it was not an acceptable solution for a number of reasons. A purpose-built clamp capable of gripping a munition and using leverage (hydraulic) to pop munitions off the bottom is believed to be a possible solution. Such a tool would be necessary with UWMM that pose a high risk of exploding if bumped. Variations of this tool could be built to accommodate a wide range of military munitions. For instance, one size could be used for smaller artillery projectiles up to a 155mm projectile and small bombs. A larger size could be used for 500-lb bombs, torpedoes, missiles and barrels. Properly designed, the larger size tool could be packaged with a marine lift bag (recovery line spool, lift bag) capable of lifting the munitions to the surface for retrieval. Munitions found in sandy areas were easily pulled off bottom.

7.1.2. Data Management

ROUMRS and EHDS operations generate a large quantity of data including, but not limited to video, GIS coordinates, descriptions of munitions, descriptions of corals, and treatment requirements. Because the amount of data was greater than anticipated, its management was not as seamless as planned. Data management (e.g., requirements, collection) must be better defined, vetted by users, and debugged before initiating field operations. During the Demonstration, data needed to be manually reviewed and summarized before it could be evaluated for use in validating the effectiveness of both the ROV and EHDS.

The ROV screen annotation, file management and data logging needs to be better documented. Additionally, a menu of best or standard practices should be developed. The development of short cuts or macro key features would improve the process in future uses. Audio recordings were not used during the Demonstration. A detailed training program for Visualsoft would also be advantageous.

7.1.3. Training

Onsite training was compartmentalized by both task and the time of mobilization, which was staggered. This meant that the operations and safety training were not provided to all personnel in the same manner at the same time. This resulted in only a few personnel having a good grasp of the entire recovery and disposal process. Cross-training operators and teams would have given the team greater flexibility in the field, and should be conducted for future similar efforts. Additional task-specific training should be provided, as necessary. Training on data collection procedures should be expanded to ensure data management can be as efficient as possible.

7.1.4. Site Logistics

Typically, the Demonstration work area is accessible by the public for fishing and recreational uses. The Army was sensitive to public uses near the Demonstration site and work areas. Therefore, it curtailed DSV operations during evening hours and weekends. By doing so, the safety zones were collapsed, allowing public to access. This access policy reduced the amount of time available for munitions treatment, excluding SAA, to five days a week. Additionally, on some weekdays, between 9:00 am and 10:20 am, DSV activities were curtailed to allow local dive shops access to dive locations near or under the DSV. This impacted Demonstration activities including cutting operations, heating of the RCBOs, and towing of salvage baskets. Although not avoidable at Ordnance Reef (HI-06), operations need to consider public access requirements and adjust the location of operations, if possible, to avoid impacting operations.

7.2. ROUMRS Equipment

7.2.1. Scaling Laser

The 10mW Laser with scaling lines was not visible beyond 1 meter in clear shallow water with high ambient light. Standard laser output for ROV's is 5mW. 50mW lasers are available for ROV's, but their use requires additional safety procedures because such lasers can cause instantaneous damage to the human eye. If scaling lasers are required for clear shallow water during daytime operations, then higher power lasers should be used and safety procedures implemented. At Ordnance Reef (HI-06) scaled lines (scaled in 1" increments) (0-14") on the front of the ROV Hopper were used to estimate each munitions size. These proved very useful for close in scaling and were readily visible on the video record.

7.2.2. Pan Tilt Actuator

The pan tilt unit from SubAtlantic had both considerable jitter and insufficient torque to lift the ROUMRS camera suite. Reverse thruster wash shook the cameras so badly the video image was sometimes barely usable. Replacement of the pan tilt actuator with a more capable unit that can accommodate the existing camera suite and that has reserve torque for camera upgrades (HDTV) is recommended.

7.2.3. ROV Tether Management

Low cost "foam noodles" and fishing floats were used to provide the buoyancy necessary to keep the ROV tether off the bottom. However, the foam noodles used lost buoyancy below 20 feet. Fishing floats, which were purchased to float the tether at depths, required close spacing to achieve buoyancy. Adding floatation creates additional drag on the cable which reduces the ROV's operating envelope in higher currents. In either case, anything fixed to the tether may become easily snared on underwater obstacles creating additional hazards. The proper fix is to procure a neutrally buoyant tether for the ROV and use a minimum number of hard floats to lift it clear of the bottom. A neutrally buoyant tether is approximately 15-20 percent more expensive than the existing tether and would require a several vehicle related modifications to implement.

Handling the ROV tether, which was done by hand, required two or three people. This is adequate for short duration and shallow water efforts, but it is not practical for deepwater and/or longer efforts. Manually tending a tether is not possible in deepwater (more than 200 feet) or in currents over 1 knot. In such situations, a winch is required. Although it was not an issue for this Demonstration, development of a deck space plan would increase efficiency, reduce lost time and minimize potentially unsafe conditions that may occur by interfering with the tether operations.

7.2.4. Lift System

Training on the lift mechanism should be performed prior to hook up and rigging of the balloon to the tow system. Additional expendable pull pins, which are used to activate the lift mechanism, should be available for the air tanks, as only one remained by the Demonstration's end. Quality control (QC) checks should be required prior to conducting lift balloon operations on future efforts.

Several methods of attaching the lift system to the salvage baskets were attempted. In all cases, the method included fixing a buoy and tag line to the lift line. Attaching a canister of line with the ROV to the salvage basket worked best. After rigging the line to the lift cable with a T-Handle shackle, a pin was pulled, and a buoy was floated to the surface with this line. This method took about 30 minutes to rig before the dive and 10 to 20 minutes to execute underwater. On one occasion, a buoy line fouled the ROV's thrusters. This resulted in several hours of down time. A simpler approach (e.g., designing the lift bag assembly with an integrated lifting cable and lift eye) would be beneficial. Using an integrated system (built into the lifting basket) would simplify this task without requiring the ROV to add additional lines.

7.2.5. Salvage Baskets

Design of the salvage baskets was driven by a concern about particle containment (i.e., releases of MC, both metals and explosives, as potentially deteriorated munitions were placed in the basket). If small particle containment is not required, the baskets' doors should be removed as they made placing munitions into the basket time consuming. The outer top cover of the salvage baskets appears to be redundant. By removing the lids, the time involved for the ROV to manipulate the frame and pin systems that hold the lids in place would be eliminated. Given the strength of water currents, the opening and closing of the lids was extremely difficult and time consuming.

One of the design requirements of the salvage basket and ROV hopper was the containment of a 3/16" diameter propellant grain. Considerable expense in design and materials were expended to meet this requirement. Although propellant grains, which were believed to have been associated with the UWMM present at Ordnance Reef, have historically washed ashore, no propellant grains observed to have been released during the Demonstration. As a result, this feature was not necessary.

Placement of the salvage baskets should be performed during slack tides. The depth and height of the salvage baskets could be reduced to three feet for better ROV access. The placement of salvage baskets was not accurate in a heavy current and several baskets flipped over during placement. Even when the salvage basket lid and pin system were removed to avoid inadvertent injuries to coral and facilitate operations, it was still safe to transport recovered munitions in the open basket without a release of MC.

Emptying the ROV hopper into a salvage basket is a useful feature that greatly reduces the amount of time required for this process. Early in the Demonstration, the ROV hopper's door mechanism was damaged beyond what was repairable in the field. As a result, the ROV hopper's contents had to be emptied piece-by-piece using the ROV's manipulator. This method took at least four times as long as simply maneuvering the ROV on top of a salvage basket and transferring the munitions from the hopper to the salvage basket using the hopper's door.

7.2.6. Acoustic Positioning

An Applied Acoustics Nexus USBL unit was rented for this Demonstration. A certain amount of training was required to get the unit to perform well. The unit's performance was satisfactory relative to its cost, and factory support was quite good. However, the unit's shortcomings became apparent during its use. These included the loss of tracking when the ROV's HPU was on, and not including a "light navigation" software package that could both display the RSV's and ROV's position on a chart overlay and output this data in a GIS friendly format. By tweaking the system, it may have been possible to fix the HPU interference problem, but the Demonstration team did not have the time or the proper diagnostic equipment in the field to do so. OII supplied HYPAC Navigation software at no cost to the client. Other efforts that use ROUMRS may require the annual purchase of a HYPAC license and training of the operational personnel or use of an alternative system. (Note: There are other, more capable USBL systems that cost considerably more than the NEXUS unit rented. However, it is recommend that other units be considered and consideration be given to having a factory representative on-site to train operators and help configure the system to the ROV, the Visualsoft data recorder, and local ship acoustic condition.)

7.3. EHDS

The preset temperatures and times used for the RCBOs, based on TM 9-1300-214, were adjusted during the Demonstration to optimize thermal treatment. Actual treatment temperatures and times varied somewhat from those of the publication.

The RCBOs were designed to slowly increase temperature based on the readings of three thermocouples and would hold temperature at a lower than desired temperature, if one of the thermocouples was faulty or reading a lower temperature. Although the temperature control was designed to promote unified heating and prevent hot spots, it resulted in lengthy ineffectual heating. This problem was fixed remotely, but in the future, it would be better to control the temperatures using a single thermocouple.

The RCBOs occasionally shut down due to ground faults. These faults were caused by both moisture and melted wiring, which was caused by high temperatures from the RCBOs when they opened. A better electrical configuration, where the wiring is placed behind the ovens and away from moisture and heat sources is needed to prevent this.

On one occasion, explosives melted and the liquid remained in the tray after the cycle was completed. Remote cameras focused on the inside of the ovens could both be beneficial and improve operator performance and safety.

Although all of the explosive fillers were disposed of during treatment in the RCBOs, some tracer compounds were found to remain in the base plates of the 5-inch projectiles. Tracer compounds, which are flammable, would normally have ignited during heating, but degradation by saltwater likely reduced the reactivity of the tracer compounds. Although the presence of tracer compound in the base plates does not pose a significant hazard, future uses of EHDS that involve treatment of 5-inch projectiles should include the addition of a remote drill press for drilling out the base plate. Adding this process would help ensure tracer compounds were eliminated prior to documenting metal remaining after treatment as MDAS

8. CONCLUSIONS

Ordnance Reef (HI-06) Technology Demonstration's objectives were met.

ROUMRS was designed assembled and integrated to manipulate or grab UWMM of different sizes in a manner that met requirements. ROUMRS proved capable of safely recovering UWMM, loading them to salvage baskets and triggering a lift mechanism. The ROV's sensors were sufficient to assist in determining the types of munitions recovered. Although several design parameters (e.g., ability to place a charge, capability to operate 24 hours, ability to contain MC, ability to operate at a depth of 300-feet) were not able to be tested, operations performed sufficiently demonstrated that ROUMRS would be able to meet these parameters.

EHDS was designed and safely operated at sea, meeting the DDESB safety requirements and complying with state and local environmental laws. After treatment, remaining metals from munitions components were documented as MDAS and recycled locally in Hawaii.

ROUMRS recovered and EHDS disposed of 74 munitions (i.e., 5-inch artillery projectiles, 40- and 100- lb bombs) and 2,300 SAA. EHDS successfully treated 150 kg (330.69 lbs) of explosives, 61 kg (134.48 lbs) of propellant, and all recovered SAA.

The cost model shows that to achieve 360 hours of bottom time ROUMRS on a 12-hour day schedule is approximately 33% less than the cost of using divers and that ROUMRS on a 24-hour day schedule is approximately 25% less than the the cost of 12-hour day ROUMRS operations.

The technology demonstrated can be used by DoD, other federal agencies, and commercial firms that conduct munitions-related activities (e.g., munitions response actions, emergency destructions, environmental surveys) both underwater and on land. The capital costs associated with procuring ROUMRS and EHDS may be an obstacle to widespread use. However, these costs are must be balanced against decreased costs of recovery operations, minimization of environmental impacts, and increased safety.

The technologies integrated into ROUMRS and EHDS are COTS equipment that is readily available. The use of commercially available components reduces difficulties associated with obtaining replacement parts and the production of new components. ROUMRS could be commercialized by a private company that could maintain the system. ROUMRS, which is full-sized, could be scaled up or down to meet requirements.

Generally, technology transfers are based on successful demonstrations. Technology transfer activities include verbal outreach and development of printed outreach materials. To assist in understanding of ROUMRS's and EHDS's capabilities, the Army intends to make this report available to DoD interested parties and the public. In addition, a peer reviewed paper on the system and the Demonstration is available in the Marine Technology Society Journal (Carton et al. 2012). The Demonstration has also been briefed at several technical meetings.

ROUMRS and EHDS provide additional tools that DoD can use to address UWMM when such munitions are determined to pose an unacceptable risk to human health and the environment. Under many circumstances, ROUMRS offers distinct operational advantages over the use of divers to recover and/or destroy UWMM. ROUMRS operations involve fewer personnel and allow for extended bottom time. Additionally, the use of ROUMRS improves the overall safety of recovery operations and decreases costs.

EHDS provides an efficient, safe, and environmentally sound means of treating recovered munitions, both at sea and on-land, reducing reliance on open detonation.

ROUMRS and EHDS each provide munitions response options that improve general and explosives safety, reduce the potential for environmental impacts, and remove explosive hazards. ROUMRS eliminates the need for and associated risks of using divers.

9. BIBLIOGRAPHY

ARA, Incorporated. 2010. Remotely Operated Underwater Munitions Recovery System (ROUMRS) Demonstration Work Plan, Prepared for Department of the Army, Office of the Assistant Secretary (Installations and Environment). Contract No. W91WAW–09–C–0168. September 2010.

ARA, Incorporated, 2011. Ordnance Reef Technology Demonstration Explosive Safety Site Plan , March 2011.

AR 385-10, The Army Safety Program, August 23, 2007

Carton, G., J. King, J. Bowers, 2012. Munitions-Related Technology Demonstrations at Ordnance Reef (HI-06), Hawaii. Marine Technology Society Journal Vol 46(1): 63-82.

Department of the Army (DA) Pamphlet 385-64, Ammunition and Explosive Standards, with Change 1, December 15, 1999

DoD Instruction 4140.62, Management and Disposition of Material Potentially Presenting an Explosive Hazard (MPPEH), December 3, 2004

DDESB (Department of Defense Explosives Safety Board), 2007. Memorandum to Deputy Assistant Secretary of the Army (Environment, Safety and Occupational Health) and Deputy Assistant Secretary of the Navy (Environment). Subject: US Army Technical Center for Explosives Safety Risk Assessment of Remote Sensing Survey and Sampling at Discarded Military Munitions Site, Ordnance Reef, Waianae, Hawaii. 20 July.

DDESB Memorandum, Subject: Approval of Interim Change to DDESB Technical Paper 16, Revision 2, September 10, 2007

Engineer Manual (EM) 385-1-1, Safety and Health Requirements Manual, November 3, 2003
EM 1110-1-4009, Military Munitions Response Actions, June 15, 2007 with Errata Sheets 1 and 2

Engineer Pamphlet (EP) 1110-1-18, Military Munitions Response Process, April 3, 2006 with IGD 06-04, March, 2006

EP 385-1-95a, Basic Safety Concepts and Considerations for Ordnance and Explosive Operations, August 27, 2004 with Errata Sheet 1 , September 22, 2006, Errata Sheet 2 , 29 June 2007 and Errata Sheet 3 , 4 Dec 07

EP 385-1-95b Explosives Safety Submissions, March 28, 2003

Engineer Regulation (ER) 385-1-95, Safety and Health Requirements for Munitions and Explosives of Concern (MEC) Operations, Military Munitions Center of Expertise (MM CX), 30 March, 2007, with Errata Sheet 1 December 2007

Epstein, J., D. Rosenblatt, A. Gallacio, and W. McTeague, 1973. "Summary Report on a Data Base for Predicting Consequences of Chemical Disposal Operations," Edgewood Arsenal Special Publication EASA 1200-12. January.

George, R., R. Gauthier, K. Denslow, A. Cinson, A. Diaz, and M. Griffin. 2008. "Contraband Detection Using Acoustic Technology." In Proceedings of the 15thth International SPIE Symposium on Smart Structures and Materials: Nondestructive Evaluation and Health Monitoring—Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure, and Homeland Security, 9–13. San Diego.

Kekaula, Hudson, 2011. "Ordnance Reef Tech Demonstration – Quick Update (via email)", To USACE POD Deputy Commander, August 2, 2011.

Mitchell, Bill 2010. "Emissions Estimates for the Destruction of Ordnance Reef UXO By ARA's Energetic Hazard Demilitarization System (EHDS)", Bill Mitchell and Associates, May 27

National Defense Center for Energy and Environment (NDCEE). 2009. Regional Sustainability Solutions (RSS) FY07, Project 3.7 Hawaii Region-Undersea Munitions Response Assessment, Final Preliminary Systems Requirements Report.

National Oceanic and Atmospheric Administration, 2007. "Ordnance Reef, Wai'anae, Hawai'i. Remote Sensing Survey and Sampling at a Discarded Military Munitions Sea Disposal Site, Final Report" Marine Sanctuaries Conservation Series NMSP–07–01. Silver Spring: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program. Silver Spring.

NOAA (National Oceanic and Atmospheric Administration) 2011. Ordnance Reef (HI–06) Coral Avoidance and Minimization of Injury Plan (CAMIP). http://www.ordnancereefhawaii.org/.../04_AppendixC_CAMIP.pdf.

U.S. Army Corps of Engineers 1996. Defense Environmental Restoration Program for Formerly Used Defense Sites (DERP–FUDS) Inventory Project Report, Off-Shore Waianae Sewage Outfall, Waianae, Oahu Island, Site No. H09HI047500. September 13, 1996.

U.S. Army Garrison, Hawaii 2011. Media Release 2011–08–02. Army Completes Demonstration at Ordnance Reef. August 5.

USATCES (U.S. Army Technical Center for Explosive Safety) 2007. Risk Assessment of Ordnance Reef, Wai'anae, Hawai'i, Remote Sensing Survey and Sampling at a Discarded Military Munitions Sea Disposal Site.

U.S. Department of Defense 2010. DoD Ammunition and Explosives Safety Standards—Department of Defense Manual 6055.9–M, 29., August

U.S. Department of Defense, (DoD) 2010. Defense Environmental Programs Annual Report to Congress, for Fiscal Year 2009, Chapter 10, Sea Disposal of Military Munitions.

U.S. Department of the Army 2011. "Environmental Assessment and Draft Finding of No Significant Impact, Technology Demonstration of Remotely Operated Underwater Munitions Recovery System (ROUMRS) and Energetic Hazard Demilitarization.

Van Ham, N., 2002. "Investigations of Risks Connected to Sea-dumped Munitions" in Chemical Munition Dump Sites in Coastal Environments. T. Missiaen and J.P. Henriet (Eds.), Federal Office for Scientific, Technical and Cultural Affairs (OSTC), Federal Ministry of Social Affairs, Public Health and the Environment, Brussels, pp. 81-93.

Wade, R.L., 2006, Presentation, "Joint Architecture for Unmanned Systems", US Army Software Engineering Directorate,

Website, Earth Trust, http://www.earthtrust.org/wlcurric/whales.html/[Online][Cited April 21 , 2010]
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