DEMONSTRATION PLAN

Cut and Capture System Technology for Demilitarization of Underwater Munitions – Open Water Test

ESTCP Project MR18-5116

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14. ABSTRACT
Munitions are encountered in a variety of underwater environments as unexploded ordnance (UXO) or munitions and explosives of concern (MEC). These items can cause unacceptable explosive risk to critical infrastructure, recreational divers, and shermen. The ordnance can also wash up on-shore and place people at serious risk of death or injury from an explosion. The purpose of this demonstration is to validate an underwater suite of tools that can be used to demilitarize underwater UXO or MEC. Note that only inert target items will be used in this demonstration.

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Acronyms

ASJ abrasive slurry jet

AWJ abrasive waterjet

BIP blow in place

DOD Department of Defense

EOD explosive ordnance disposal

ESS Explosive Safety Specialist

HASP health and safety plan

HC high capacity

HMI human-machine interface

MDAS Material Documented As Safe

MEC munitions and explosives of concern

MTBF mean time between failures

NDSTC Naval Diving and Salvage Training Center

NEDU Navy Experimental Diving Unit

NMC Navy Munitions Command

NSA Naval Support Activity

NSWC-PCD Naval Surface Warfare Center-Panama City Division

PC Panama City

RDX Research Department eXplosive or Royal Demolition eXplosive

RMS root mean square

TNT Trinitrotoluene

UXO unexploded ordnance

WJ waterjet

1 Introduction

Munitions are encountered in a variety of underwater environments as unexploded ordnance (UXO) or munitions and explosives of concern (MEC). These items can cause unacceptable explosive risk to critical infrastructure, recreational divers, and fishermen. The ordnance can also wash up on-shore and place people at serious risk of death or injury from an explosion [1]. The purpose of this demonstration is to validate an underwater suite of tools that can be used to demilitarize underwater UXO or MEC. Note that only inert target items will be used in this demonstration.

1.1 Background

Demilitarization of underwater munitions currently requires either *in situ* remediation through use of countercharges or jet perforators placed by Explosive Ordnance Disposal (EOD) divers or by the recovery of the hazardous ordnance for demilitarization on the surface. *In situ* detonation is most frequently used, but completely destroys the local marine ecosystem (e.g., protected or sensitive corals, fish, and mammals), kills or damages marine flora and fauna out to tens of meters, as shown in Jennings and Polunin [2], and can severely injure or deafen marine mammals, such as whales, dolphins, and porpoises out to 5 kilometers, as shown in Ketten [3], Klima et al., [4], and Yelverton et al., [5].

Use of *in situ* detonation is often constrained by potential blast effects that will damage sensitive habitats and cultural resources (e.g., shipwrecks) and blast acoustics that may harm sensitive biota (e.g., marine mammals) according to Keevin and Hempen [6]. It is often preferable to leave munitions in place from an explosives safety and environmental protection perspective unless such munitions pose an unacceptable risk to human safety. Even then it is often preferable to leave the munition casings in place but remove or reduce the explosive hazard in order to mitigate the potential risk of damage to the local microbiome such as coral reefs. The ecotoxic potential, as shown in Lotufo and Kuperman [7] and Sunahara, et al., [8], for the environmental release of organic chemical fillers (e.g., nitroaromatic and nitramine explosives such as TNT and RDX) from continuously corroding munitions also must be addressed.

Recovery of live munitions from the subsurface may result in an unintended detonation from activating the fuzing mechanism which may also destroy the maritime environment. Furthermore, recovery by divers places personnel at risk from both the ordnance and from repetitive and extended dive times. Each of these scenarios is undesirable and has high risk associated with them.

A technology that utilizes high-pressure waterjets to render a munition safe *in situ* could reduce the risk to response workers and the public and avoid potentially significant and costly environmental impact. Such a technology would be highly beneficial to the U.S. Department of Defense (DOD) as it begins to address underwater munitions at places with sensitive marine environments and high public access, like Culebra, Vieques, and Hawaii. Therefore, Gradient Technology will demonstrate its high-pressure waterjet demilitarization technology in an open water environment.

1.2 Objective of the Demonstration

The objective of this demonstration is to validate an underwater suite of tools that can be used to render safe underwater UXO and MEC. Testing will be conducted on inert Navy 5-inch/38-caliber projectiles in an open water environment. The suite of tools to be tested will accomplish the following objectives:

1. **Clean** an inert munition of external bioencrustations using a high-pressure waterjet cleaning tool and three-axis underwater gantry,
2. **Position and attach** a cut and capture apparatus on the target item using a three-axis underwater gantry,
3. **Cut** an access hole in the side of the target item using a high-pressure entrainment-style abrasive waterjet cutting head and remove the resulting steel plug with a magnetic head,
4. **Wash out** the internal contents of the target item using a high-pressure washout head, and
5. **Capture** the effluent generated during high-pressure cutting and washout using a continuous flush and capture tank.

1.3 Regulatory Drivers

The demonstrated technology offers an environmentally friendly alternative to blow-in-place (BIP) practices historically utilized to render safe underwater UXO and MEC.

2 Technology

Gradient Technology has extensive experience in using high-pressure abrasive waterjet (AWJ) to demilitarize munitions on land. The onshore use of AWJs is a well-proven technology for cutting munitions and capturing their contents. Since 1991 AWJs have been used to safely demilitarize munitions without incident. Currently, Gradient Technology is utilizing a fully integrated and automated high-pressure waterjet projectile accessing and washout system at NSA-Crane. This system was designed, fabricated, integrated, and installed by Gradient Technology and has been operating since 2001. This projectile accessing system, shown in Figure 1, uses high-pressure abrasive waterjets with garnet abrasive to cut out the corroded base fuzes from large caliber U.S. Navy projectiles containing Explosive D and sensitive picrate salts, the corrosion products of the filler. In a second processing step, high-pressure waterjets at 55 *ksi* are used to completely wash out the explosive contents of the projectiles. This one processing line alone has processed over 300,000 projectiles, ranging in size from U.S. Navy 3-inch/50-caliber to 8-inch/55-caliber projectiles, to date without issue.

Figure 1. Automated AWJ cutting and washout system processing 8-in/55-cal HC rounds.

Over the past ten years, Gradient Technology has been adapting this AWJ technology for use underwater [9–12]. This adaptation has involved the integration of a variety of tools into a package that can be deployed and operated from the surface. It is this suite of tools that will be demonstrated.

2.1 Technology Description

The proposed proprietary technology for *in situ* demilitarization of munitions utilizes the following tools/technologies:

1. Three-axis underwater gantry for moving the tool package around the target item,
2. High-pressure waterjet cleaning tool for removing the bioencrustations or debris from the surface of the target item,
3. High-pressure entrainment-style abrasive waterjet cutting head for cutting an access hole in the side of the target item,
4. Magnet for removing the steel plug resulting from cutting,
5. High-pressure washout head for removing the internal contents of the target item, and
6. A continuous flush and capture tank for capturing the effluent generated during high-pressure cutting and washout operations.

A three-axis underwater gantry holds the tool package and allows for positioning it near or on the target item. The gantry and tool package are shown in Figure 2. This gantry allows for movement of the high-pressure waterjet cleaning tool for removing the bioencrustations or debris from the surface of the item of interest. Figure 3 shows the high-pressure waterjet cleaning tool that will deliver approximately two gallons per minute of 55 *ksi* water in a plurality of jets directed at the surface to be cleaned.

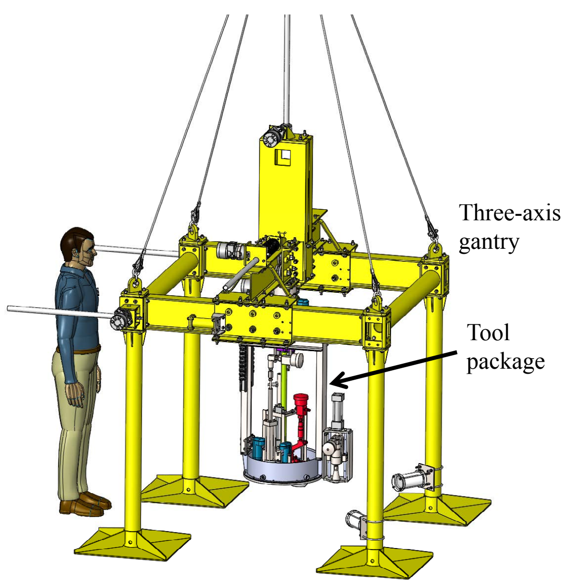

Figure 2. Integrated system consisting of a three-axis underwater gantry and the tool package (computer model).

Figure 3. High-pressure waterjet cleaning tool.

The high-pressure entrainment-style abrasive waterjet cutting head used for cutting an access hole in the side of the target item utilizes approximately two gallons per minute of 55 ksi water and directs a single jet of water at the surface to be cut. Garnet abrasive is introduced into the high-pressure water stream via the Venturi effect at a rate of approximately one pound per minute. The abrasive is subsequently accelerated and impinges on the surface and erodes the material to be cut. The operating principle is captured in the schematic shown in Figure 4 [13].

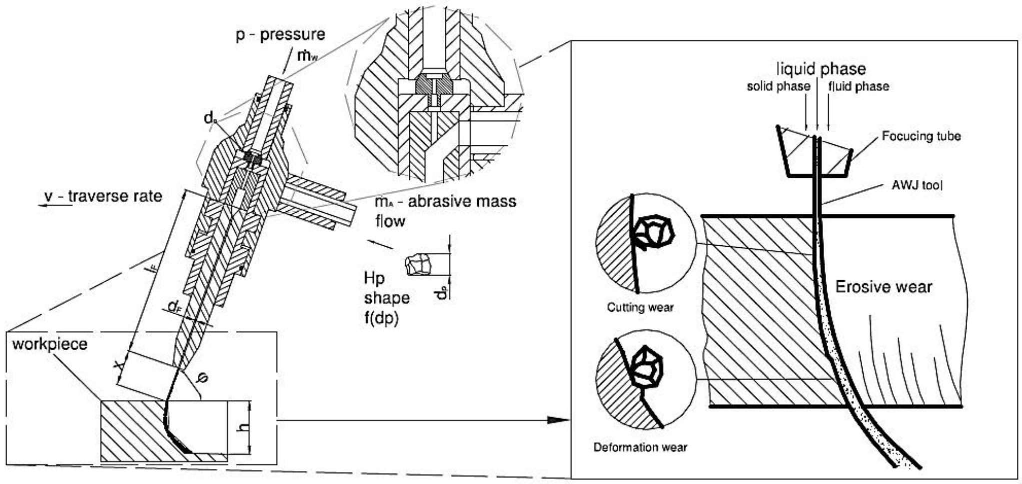

Figure 4. The high-pressure entrainment-style abrasive waterjet cutting principle [13].

The high-pressure washout head generates a high velocity water stream similar to the cleaning tool. This washout head is, however, smaller and is articulated into the target item via the access hole provided by the cutting operation. The high velocity water streams are used to erode the material inside the target item so that small pieces of the material can be flushed out of the internal cavity.

Figure 5 is a representation of the tool package that contains the high-pressure entrainment-style abrasive waterjet cutting head, magnet, and high-pressure washout head all located on a turret. The high-pressure waterjet cleaning tool is attached external to the tool package. This tool package utilizes a turret and a multitude of servo motors to allow for turret rotation/translation and appropriate tool control. In addition, the piping for the continuous flush and capture tank equipment for collecting the effluent generated during high-pressure cutting and washout operations is attached to the tool package below the turret.

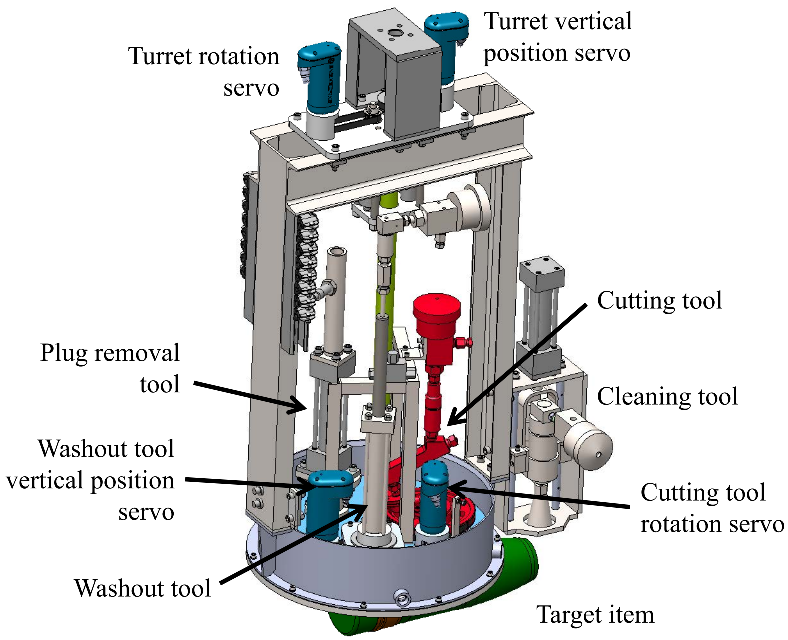

Figure 5. The integrated underwater tool package for *in situ* demilitarization of munitions (computer model).

The tool package shown in Figure 2 is lowered from the surface and placed over the item of interest. All support equipment for the system will be located above water. This equipment includes:

1. High-pressure waterjet intensifier pump for generating high-pressure water,
2. Abrasive hopper for containing the required abrasive and delivering it to the abrasive feeder,
3. Abrasive feeder that dispenses abrasive at a controlled rate into a plastic line that is routed down to the cutting head,
4. Hoist-type deployment system for lowering the equipment into the test tank, and a
5. Control panel housing all control hardware for operations.
6. Human-machine interface (HMI) for operating the equipment.

In addition to this equipment, a water source, electrical power source, and compressed air source are needed and are available at the site. A simplified overall process schematic is shown in Figure 6.

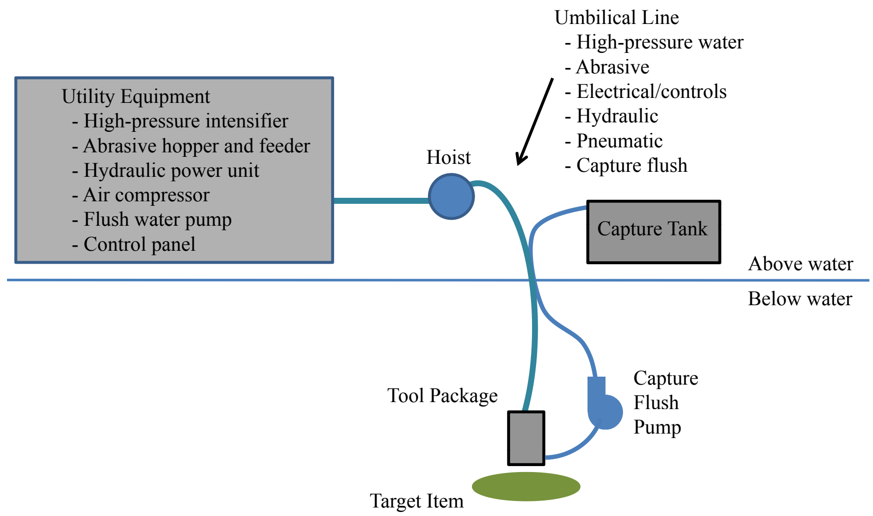

Figure 6. Overall process schematic of the system to be demonstrated in Panama City.

Overall, a majority of the technology pieces contained in the tool package have been successfully utilized above water for demilitarization. Over the past ten years, Gradient Technology has adapted this technology for the underwater environment. This demonstration will validate the integrated tool package in an open water environment.

2.2 Advantages and Limitations of the Technology

The high-pressure entrainment-style abrasive waterjet system used in this demonstration uses a specialized cutting head that entrains (mixes) the abrasive and water together less than 3 *inches* from the cutting tip using a Venturi-type mixer. These entrainment waterjets have much higher reliability and uptime than premixed abrasive slurry jet (ASJ) systems and are now the industry standard in North America. The ASJ systems require pressurizing tanks of liquid abrasive slurry to high pressures and then piping the abrasive mass through the pipes and valves to the cutting tip. The system pressure is generally limited to the fatigue limits of the pressure vessels holding the abrasive slurry. The entrainment style cutting head, on the other hand, allows extremely high water pressures to be used in AWJ when compared to ASJ systems (up to 100 *ksi* vs 10 *ksi*) with accompanying proportional increases in cutting efficiency. The abrasive in an AWJ doesn't drop out of suspension and plug the piping and valves like in an ASJ since it is added by entrainment and not held in slurry form.

3 Performance Objectives

There are seven main performance objectives planned for the demonstration test. They contain both qualitative and quantitative metrics as shown in Table 1.

Table 1. Performance Objectives

Performance Objective	**Metric**	**Data Required**	**Success Criteria**
Quantitative Performance Objectives			
Equipment reliability	Failure rate per hour Major: Requires repair Minor: Requires reset	• Hours operations • Number of major failures • Number of minor failures	 $MTBF_{major} > 3\ hr$ $MTBF_{minor} > 1\ hr$
Cleaning of the target	Percentage of area reduced to 6.35 mm RMS or less	• Initial target area • Post-WJ area RMS	90% average acceptable RMS
Waterjet washout of munition constituents	Percentage of material removed	• Initial mass • Post-washout mass	80% average removal
Qualitative Performance Objectives			
Capture of munition constituents	Percentage of material captured	• Initial fill mass • Mass captured	80% average capture
Attachment to target	Percentage successfully attached	• Items attempted • Items successful	$P_{attach} > 80\%$
Abrasive waterjet cutting of access hole	Percentage successfully cut	• Items attempted • Items successful	$P_{cut} > 80\%$
Tool positioning with sonar imaging	Observed utility of sonar imaging for positioning	• Observations	
Abbreviations: $MTBF$ = meant time between failures RMS = root mean square			

3.1 Objective: Equipment Reliability

The reliability of the equipment used to conduct demilitarization will affect rates and operational cost. The system has been engineered to utilize reliable components to minimize downtime. Since the system used in this demonstration is highly integrated, one component failure can significantly impact the performance of the entire system. Therefore, redundancy has been built into critical areas of the system to alleviate the halting of operations. For example, the high-pressure waterjet intensifier pump used to generate high-pressure water for the three downstream tools (cleaning head, cutting head, and washout head) has been fitted with a redundant intensifier. The intensifier contains components such as seals that periodically fail and their replacement can take a few hours by a trained technician. If a redundant intensifier is incorporated into the system and the in-use intensifier does fail, changing over to the redundant intensifier can be accomplished in minutes by turning a few manual valves. Operations are thus only interrupted briefly and maintenance on the failed intensifier can commence.

3.1.1 Metric

The number and type of major and minor failures are used to quantify a mean time between failures. A major failure is one requiring repair whereas a minor failure is one requiring a reset.

3.1.2 Data Requirements

The number and type of major and minor failures will be recorded for all tests.

3.1.3 Success Criteria

The objective will be met if the mean time between major failures is greater than 3 *hours* and the mean time between minor failures is greater than 1 *hour*.

3.2 Objective: Cleaning of the Target

Target item surface roughness such as bioencrustations require removal to allow proper attachment of the tool package. Proper attachment is required to increase the amount of material collected in the capture system. Successful execution of this objective is operationally important because the results impact the ability of the system to meet the subsequent objectives. If the target is not adequately cleaned, (1) a thicker amount of material must be cut resulting in longer cut times, (2) the magnet used to remove the cut plug may not be strong enough to hold it, and (3) the tool may not properly attach to the target and could allow the munitions constituents to leak into the surrounding environment as opposed to being captured.

3.2.1 Metric

The surface roughness is quantified with an instrument such as a depth gauge or an optical stereo microscope.

3.2.2 Data Requirements

The surface roughness data collected is a direct measurement of the required information.

3.2.3 Success Criteria

The objective will be met if 90% of the cleaned area has a surface roughness of less than 6.35 mm.

3.3 Objective: Waterjet Washout of Munition Constituents

Ideally, it is desired to remove all of the fill contained inside a munition. However, in reality, a portion of the fill may not be easily removed in a timely manner and it is expected some material will remain in the item after washout. The time required for complete removal of the munition energetic fill will depend upon the size and internal configuration of the target item. This demonstration focuses on the common Navy 5-inch/38-caliber projectile that has no base or nose fuze. In addition, a three-orifice washout head has been selected so that the entire cavity can be washed when entering the item from the side; this will be verified in this demonstration. Other target item configurations may require longer washout times coupled with different washout head orifice configurations to achieve complete washout. Lastly, there could be situations in which complete washout is not required to render the target item safe. Operationally, Gradient Technology's goal is to achieve complete washout, however, this comes at the potential expense of washout time. Although difficult to quantify during the demonstration, the relationship between washout rate and the amount of material remaining in the target item will be assessed.

3.3.1 Metric

The mass of material removed is quantified by difference between the initial and final weight of the target item.

3.3.2 Data Requirements

The mass of the target item before and after washout is measured and the difference represents the mass removed. Since the initial mass is recorded, the fraction removed can be determined.

3.3.3 Success Criteria

The objective will be met if more than 80% of the munition constituents are removed.

3.4 Objective: Capture of Munition Constituents

Ideally, it is desired to collect all of the fill removed from the munition. However, in reality, a portion of the fill may leak from seals and, as a result, will not be collected in the capture system. Operationally, there are two techniques that can be used to collect the washed material. Both techniques utilize a pump to pull slurry from the tool package chamber; it is desired to pull the slurry from the chamber as opposed to pumping water through the chamber so that the chamber experiences negative relative pressure (across the seal) as opposed to a positive relative pressure. The difference between the two techniques arises at the discharge of the pump. For one technique, the discharge of the pump is plumbed to a surface tank to hold the slurry. In the second technique, the pump discharge is connected to an underwater bladder located near the tool package. This technique is more applicable for deep water operations when the transfer of the slurry long distances to the surface becomes less efficient. This demonstration will utilize a surface tank to collect the washed out material.

3.4.1 Metric

Qualitatively observe the amount of inert fill lost to the environment. During the first demonstration, any leak of inert fill to the surroundings was easily observed with cameras. As a result, the underwater cameras and associated lighting will be used to monitor leakage.

3.4.2 Data Requirements

This is a purely qualitative observation. If leakage is observed, the quantity will be estimated.

3.4.3 Success Criteria

The objective will be met if more than 80% of the munition constituents removed are collected.

3.5 Objective: Attachment to Target

Proper attachment of the tool package to the target is important for two reasons. First, proper attachment is required so that proper positioning of the individual tools is achieved. Second, proper attachment is required so that efficient capture is achieved. Proper cleaning of the target item is critical for achieving this objective. In addition, the performance of the positioning system is critical so that the tool package can be placed at the desired point on the target item. Therefore, successful operation of both the cleaning head and positioning system will lead to achievement of this objective.

3.5.1 Metric

Qualitatively observe attachment as well as capture during cutting to determine if there is significant observable leakage.

3.5.2 Data Requirements

This is a purely qualitative observation.

3.5.3 Success Criteria

The objective will be met if more than 80% of the attachments are deemed sufficient.

3.6 Objective: Abrasive Waterjet Cutting of Access Hole

An access hole is required to be cut into the target item so that the fill can be removed. The access hole is cut using an entrainment-style abrasive cutting head. The cutting head is integrated into the tool package such that a fixed-diameter hole is cut. The cutting head is also mounted at an angle so that the resulting plug does not drop into the cavity of the target item; this allows for the magnet to remove the steel plug. If there is a place on the circumference of the cutting path that is not completely cut, the magnet will not remove the plug. Raising and lowering the tool package for inspection can be utilized where extremely accurate repositioning of the tool package on the target item is not needed. However, accurate repositioning is required for continuing a cut that may not have been complete. Therefore, a small inspection camera has been implemented in the tool package chamber for confirming the magnet has removed the cut plug.

3.6.1 Metric

Qualitatively observe that a hole was properly cut in the target.

3.6.2 Data Requirements

After a cut is complete and the magnet has been used to remove the cut plug, the tool package can be readily raised to observe the resulting access hole.

3.6.3 Success Criteria

The objective will be met if more than 80% of the cuts yield a usable access hole.

3.7 Objective: Tool Positioning with Sonar Imaging

The utility of sonar imaging in positioning the tool package on the target items will be qualitatively assessed. A pair of Aris Explorer 3000 sonar imaging systems will be mounted on the tool package and used in conjunction with cameras to position the tool package on the target items. As a result, the utility of sonar imaging can be determined. Sonar imaging could be useful and likely required in low-visibility conditions underwater.

3.7.1 Metric

Qualitatively assess the utility of sonar imaging in positioning the tool package on the target items.

3.7.2 Data Requirements

This is purely observation based.

3.7.3 Success Criteria

The objective will be met if it is determined that this sonar imaging system can supplant visual observation (cameras).

4 Site Description

A controlled environment for testing was utilized in the first demonstration. In this demonstration, the system will be tested in a somewhat less controlled environment. The pertinent details of this site are subsequently documented. Note that the Health and Safety Plan associated with this demonstration and site is contained in Appendix A. Project points of contact are included in Appendix B.

4.1 Site Selection

The site selected for the second demonstration is Naval Support Activity (NSA) Panama City, Florida. A site map is shown in Figure 7. The test site location on-board NSA Panama City will be Alligator Bayou in approximately 10 FSW as shown in Figure 8.

This location was selected because of the fairly flat hard sandy bottom, fairly clear water and because it is protected from winds and waves from St. Andrew's Bay. In addition, there is easy access to a fixed gantry crane, fresh water, power, and pier space for lay down of equipment. Four weeks have been allotted for this demonstration. Two weeks for mobilization, set up, and initial testing of the system, one week for the demonstration and, lastly, one week for demobilization. Weather days and equipment down time have been factored in as well.

Figure 7. NSA Panama City, Alligator Bayou – location of second demonstration.

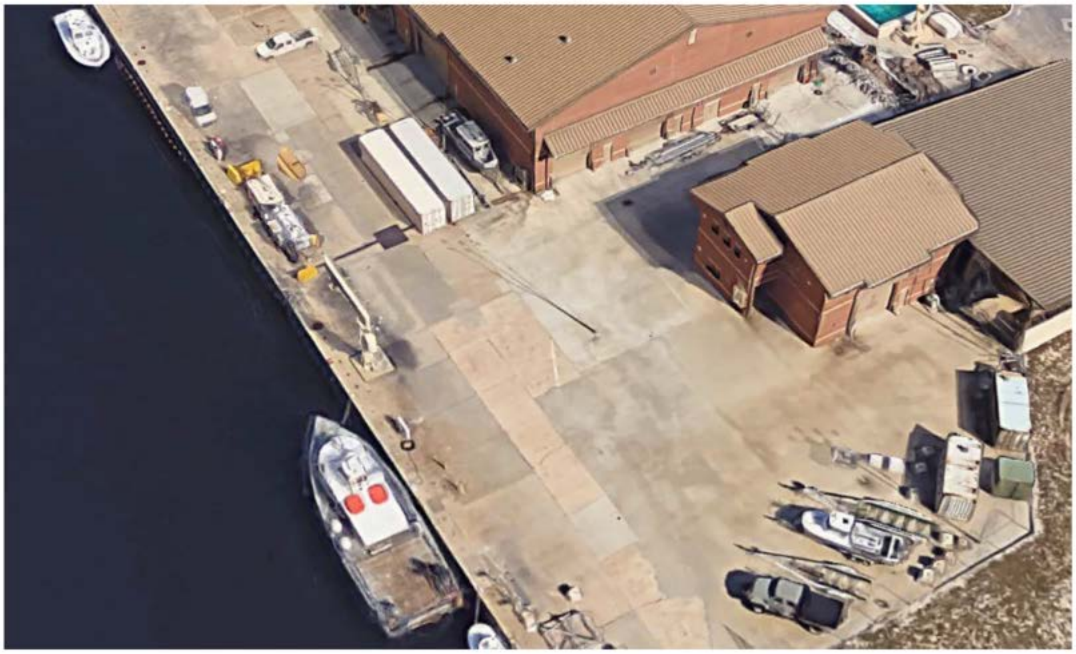

Figure 8. Overhead view of pier and gantry crane where the open water demonstration will occur.

4.2 Site History

Naval Support Activity Panama City has its origins in the mine countermeasures research conducted during World War II at the U.S. Naval Mine Warfare Test Station, Solomons, MD. In July 1945, the station was moved from Maryland to Florida to occupy a 373 acre tract along St. Andrew Bay.

Over the ensuing decades the base footprint grew to its current size of more than 650 acres and underwent a myriad of name changes until it reorganized under Commander, Navy Installations Command in October 2003. The base was renamed Naval Support Activity Panama City (NSA PC) reporting to the Commander, Navy Region Southeast, however the mission still remains rooted in its origins of research and development, testing and evaluation, and Navy diving.

The primary mission of NSA PC is to provide, operate, and maintain facilities, provide defense and physical security of critical infrastructure, and provide operational support to the Fleet, Fighter and Family, and supported commands.

Major tenants include Naval Surface Warfare Center-Panama City Division (NSWC-PCD), Naval Diving and Salvage Training Center (NDSTC), Navy Experimental Diving Unit (NEDU), and U.S. Coast Guard Station Panama City. Together, NSA PC employs more than 4,000 civilian and military personnel with an annual payroll of more than $466 million. Additionally, the base contracts for local goods and services which amounts to more than $600 million annually in economic impact.

Throughout its existence, NSA Panama City has continued to evolve to meet the demanding requirements of the U.S. Navy – to defend today and to plan for tomorrow in response to national needs.

5 Test Design

The open water demonstration will commence after all utility equipment has been placed, connected, and confirmed to be operational. This equipment includes the high-pressure intensifier pump, abrasive delivery system, hydraulic power unit, capture tank, control system, and generator. This equipment will be placed on the pier near the crane used to hoist the tool package into and out of the water.

5.1 Conceptual Experimental Design

Each experiment requires the successful execution of the following five steps:

1. **Clean** an inert munition of external bioencrustations using a high-pressure waterjet cleaning tool and the three-axis underwater gantry,
2. **Position and attach** the tool package on the target item using a three-axis underwater gantry,
3. **Cut** an access hole in the side of the target item using a high-pressure entrainment-style abrasive waterjet cutting head and remove the resulting steel plug with a magnetic head,
4. **Wash out** the internal contents of the target item using a high-pressure washout head, and
5. **Capture** the effluent generated during high-pressure cutting and washout using a continuous flush to a capture tank.

Each step will be conducted until advancement to the next step can be achieved. If at any point it is determined that the next step cannot be achieved due to issues with the previous step, a new target item will be processed. The operational parameters used in the previous demonstration will be used. These include the following:

1. Traverse rate of cleaning head = 1 in/min.
2. Water pressure for cleaning head, cutting head, and washout head = 60 ksi.
3. Abrasive feed rate for cutting = 1.25 lb/min (56%).
4. Cutting head rotational rate = 0.6 RPM.
5. Washout head traverse rate = 0.25 in/min.

The first phase of testing will occur in the shop test tank located on the pier as used in the previous demonstration (Figure 9). Three inert projectiles will be processed to confirm all utilities and the tool package are working properly. Upon confirmation of proper operation, testing will commence in open water off of the pier with the remaining inert target items. Initially, the gantry crane will be used to deploy the tool package and subsequently retrieve it so that this operation can be safely and repeatedly performed. Next, inert target items will be processed in open water.

Figure 9. Shop test tank containing the tool package.

For this demonstration, 48 inert target items will be prepared and sent to the site. The preparation of these items is detailed in Section 5.4 and summarized in Table 3. All items will have a plate welded on the base and nose to cover pre-existing holes. Of the 48 items, 16 will simply be capped without being loaded with the inert fill. These target items are used to conduct cutting, plug removal, and simulate washout. Twenty-six of the items will be loaded with inert fill so that cutting, plug removal, and washout can be tested. Lastly, six of the items will be partially covered in concrete so all process steps can be tested on each of those items. Figure 10 shows a concrete-covered item that has been partially cleaned with the cleaning head.

Figure 10. Concrete-covered inert target item after partial cleaning.

For the open water demonstration, two approaches will be used for placing the inert target items. The first approach, as was used in the first demonstration, involves placing three target items in a cradle that is connected to the tool package. This approach is beneficial since the target items can be deployed and retrieved with the tool package. This approach will be used first to process a multitude of target items. Figure 11 shows three target items in the cradle from the first demonstration. The second approach will utilize independent placement of the target items directly on the floor. Divers will be used to place the items directly on their sides on the floor in a region within reach of the tool package; note that the tool package has approximately a 3-foot by 3-foot operating window. As a result, the gantry crane does not have to be able to place the tool package gantry in an exact position. After placement of the tool package over a given target item, the tool gantry will be used to attach the tool to the target item. After attachment, the tool package will be used to process the item. This approach will allow for testing in a more realistic operational scenario. Note that cameras and lights are attached to the tool package for visualization during processing. The usefulness of sonar imaging as described in Objective 3.7 will be assessed through processing some inert target items with the cameras turned off. The quantity processed in this fashion will be determined during the demonstration.

Figure 11. Cradle for holding three target items.

Lastly, the six concrete-covered item will be processed. Three of these will be processed utilizing the cradle and the remaining three will be processed directly on the floor. Table 2 summarizes the techniques in which the 48 inert target items are to be processed.

Table 2. Target Item Preparation Summary

Item Numbers	Item Positioning	Location
1, 21, 22	Cradle	Test Tank
2, 23, 24	Cradle	Open Water
3, 25, 26	Cradle	Open Water
4, 27, 28	Cradle	Open Water
5, 29, 30	Cradle	Open Water
6, 31, 32	Cradle	Open Water
7, 33, 34	Cradle	Open Water
8–14	Floor	Open Water
35–48	Floor	Open Water
15, 17, 18	Cradle	Open Water
16, 19, 20	Floor	Open Water

At this point, it is anticipated that the equipment will be set up and tested in the shop test tank at the site during the week of July 6, 2020. The week of July 13, 2020, will be used to conduct the demonstration on the target items. An extra week has been accounted for in case of delays due to weather. If that week is not needed, the equipment would be demobilized the week of July 20, 2020. Overall, the complete demonstration is expected to require three to four weeks to complete and will process approximately 48 target items.

At the Naval Support Activity (NSA) Panama City, Florida, four key personnel will be facilitating the demonstration with Gradient Technology. These individuals are as follows:

- Rick Stynar – Senior Test Director, NSA Panama City
- Jason Tebault – Test Director (alternate), NSA Panama City
- Matthew Warren -– Test Director (alternate), NSA Panama City
- Ismael Mendoza-Perez – Test Support, Safety Observer, NSA Panama City

The recent Coronavirus pandemic will impact the manner in which this demonstration is conducted. All personnel will be required to follow NSA-Panama City policies in place at the time of the demonstration. In addition, CDC guidelines including the use of a face covering and social distancing will be adhered to at the site. Since the situation and, as a result, the guidelines are continually changing, final protocols will be established at the onset of the demonstration to ensure the safety of everyone involved.

5.2 Statistical Experimental Design and Data Analysis

Many of the objectives of this demonstration are based on success or failure of a given operation. As a result, a set of Bernoulli trials are conducted and it is assumed that the trials are independent from each other and the probability of success doesn't change from trial to trial. If this assumption is true, which is the case for our demonstration, then the number of success in Bernoulli trials has a binomial distribution. There are two important equations that are used to describe the binomial distributions. Equation 1 is the probability mass function:

$$Pr(X = i) = \frac{n!}{i!(n-i)!} \cdot p^i \cdot (1-p)^{n-i} \tag{1}$$

where Pr is the probability of getting $X = i$ successes when n Bernoulli trials are conducted in which each trial has p probability of success. For example, if 10 trials are conducted ($n = 10$) and the probability of success of an individual trial is 50% ($p = 0.5$), then the probability of observing 6 successes ($i = 6$) is 0.205.

Equation 2 is the cumulative distribution function:

$$1 - C = \sum_{i=0}^{r} \frac{n!}{i!(n-i)!} \cdot R^{n-i} \cdot (1-R)^i \tag{2}$$

where C is the confidence level, r is the number of failures, i and n are again the number of successes and Bernoulli trials respectively, and R is the reliability ($R = p$). From an experimental design perspective, equation 2 can be used to determine the number of allowable failures (r) for n Bernoulli trials with a confidence level C and a reliability of R. For example, if 48 Bernoulli trials are conducted, a confidence level of 95% is desired, and the reliability of the equipment is expected to be at least 80%, then the number of allowable failures (r) can be calculated; the result for this example is four failures. From a data analysis perspective, the reliability is not known. However, if n Bernoulli trials are conducted and the number of successes (i) are recorded, equation 2 can be used to calculate the reliability. For example, if 48 Bernoulli trials are conducted and 44 successes are observed, the reliability with a 95% confidence level is 82%. Therefore, equation 2 will be used to analyze data collected in this demonstration.

5.3 Site Preparation

The primary activity related to site preparation involves the set up of all equipment required to conduct the demonstration. Figure 12 shows the pier where the equipment will be located. Figure 13 shows a view where the generator and high-pressure pump will be located. Fresh water is available from this building also. A high-pressure water line will be run from the high-pressure pump to the tool package. Figure 14 shows the gantry crane that will be used to deploy the tool package. Figure 15 shows the area where all other utility equipment will be located. Lastly, Figure 16 shows underwater views of a target on the floor where the demonstration will occur. As shown in this figure, the floor is fairly flat and there is decent visibility.

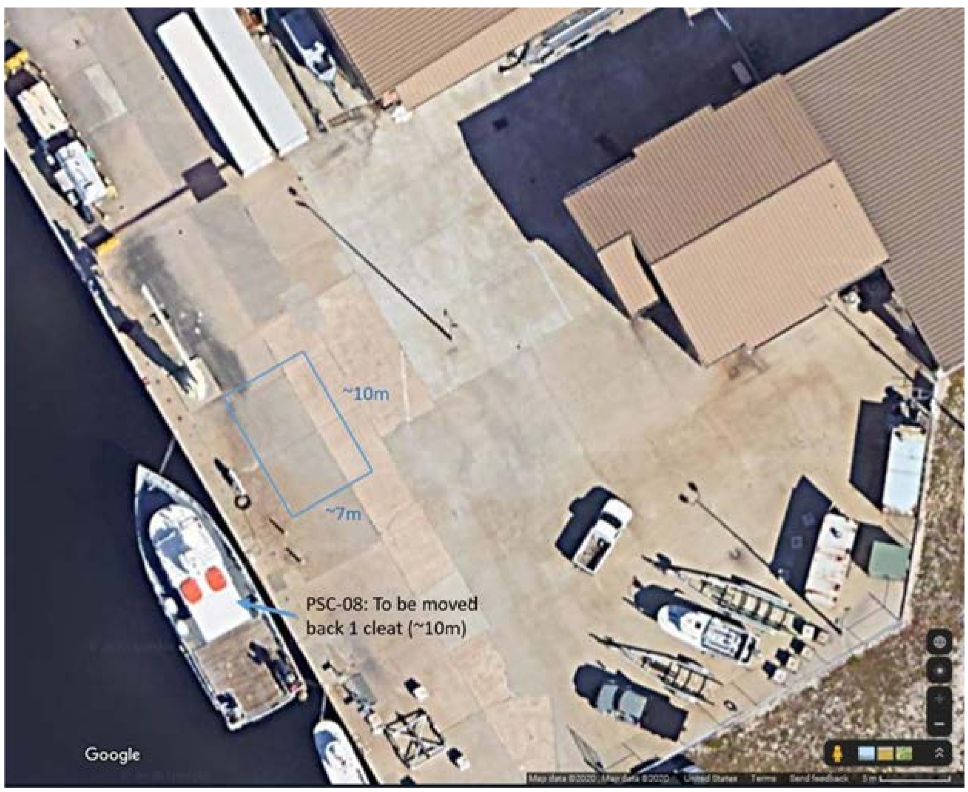

Figure 12. Pier location where all equipment will be located.

Figure 13. Bayou is directly behind photographer and the crane is to the left; Building 582 is on the right and is where the generator and high-pressure pump will be located.

Figure 14. Gantry crane that will be used to deploy the tool package.

Figure 15. Area for locating the utility equipment.

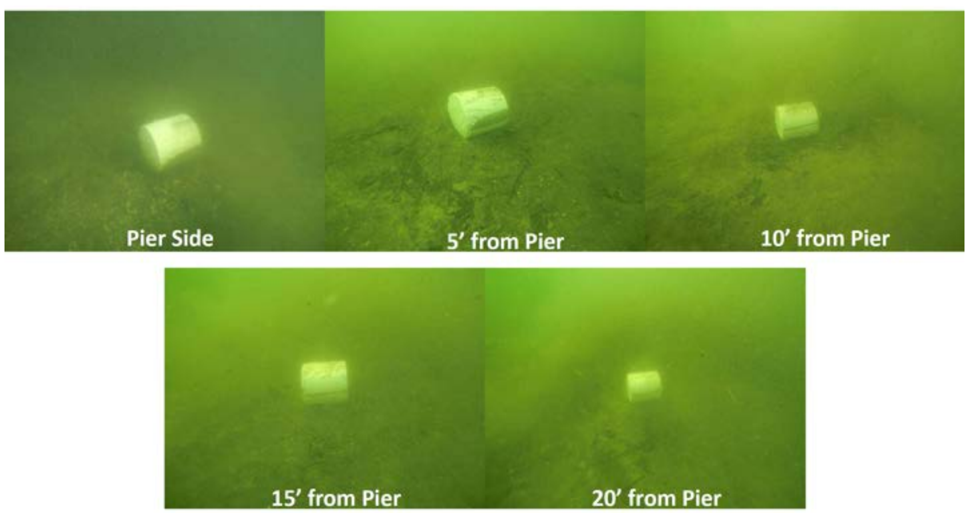

Figure 16. View of a target item on the floor off of the pier where the demonstration will occur.

5.4 Test Item Preparation

The target items will be inert Navy 5-inch/38-caliber projectiles as shown in Figure 17.

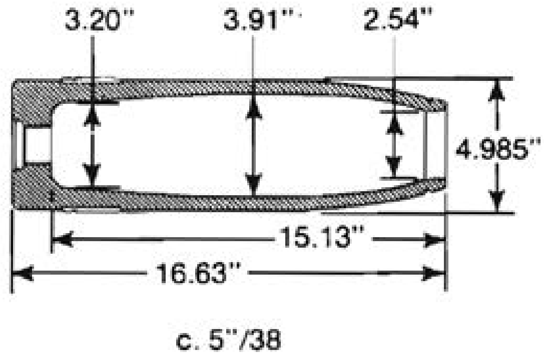

Figure 17. Nominal dimensions of Navy 5-inch/38-caliber projectiles.

Figure 18 shows the projectile bodies that will be used to create the target items. These Navy 5-inch/38-caliber projectiles have already been demilitarized by Gradient Technology using the high-pressure waterjet projectile accessing and washout system at NSA-Crane. The hole in the bottom of the projectile where the base fuze was located will be plugged by welding in a piece of steel. The nose opening will be welded shut with a circular plate after the item is pressed with inert fill.

Figure 18. Demilitarized Navy 5-inch/38-caliber projectiles that will be used for target item creation.

Concrete will be cast in a mold around six of the inert projectiles after filling with microcrystalline cellulose. The concrete is prepared by mixing Type 1 Portland cement, washed plaster sand aggregate (mason sand), and water to achieve a compressive strength of

22 $\frac{kN}{m^3}$. The concrete mixture composition is 24.7 $wt\%$ cement, 13.6 $wt\%$ water, and 61.7 $wt\%$ sand.

The energetic simulant to be pressed into the inert Navy 5-inch/38-caliber projectiles will consist of microcrystalline cellulose. This material is biodegradable and insoluble in water. The microcrystalline cellulose is procured from Alfa Aesar (stock number A17730) and is shown in Figure 19. The inert fill is incrementally poured into the projectile body through the nose and pressed to 20 $tons$ using a hydraulic press. The hydraulic press is shown in Figure 20. Table 3 summarizes the preparation of the target items.

Figure 19. Microcrystalline cellulose to be used as the inert fill in the target items.

Figure 20. Hydraulic press for pressing the inert fill into the target items.

Table 3. Target Item Preparation Summary

Item Numbers	Inert Filled	Concrete Covered
1–14	NO	NO
15–16	NO	YES
17–20	YES	YES
21–48	YES	NO

After all 48 inert target items have been prepared, they will be shipped to Navy Munitions Command Det Panama City (NMC). NMC personnel will inspect them to insure they are Material Documented As Safe (MDAS) utilizing the paperwork that has already been sent to them and the documents that are with the shipment. Next, NMC personnel will call Chris Canavan, Explosive Safety Specialist (ESS) and the Rick Strynar, Test Director, when it arrives and they will go to NMC and claim them. The items will be transferred to the pier test site for our use.

5.5 System Specification

The core of the technology to be demonstrated involves the tool package as previously shown in Figure 5. The first tool to be tested is the cleaning head. The purpose of this tool is to remove bioencrustations from the target item surface so that the turret containing the other tools can be adequately sealed on the target item. Figure 21 shows the tool package with the cleaning head in a lowered position above the target item. The three-axis gantry is used to move the tool package, and hence, the cleaning head over the target item. Figure 22 shows the cleaning head orifice arrangement where the high-velocity water jets emanate.

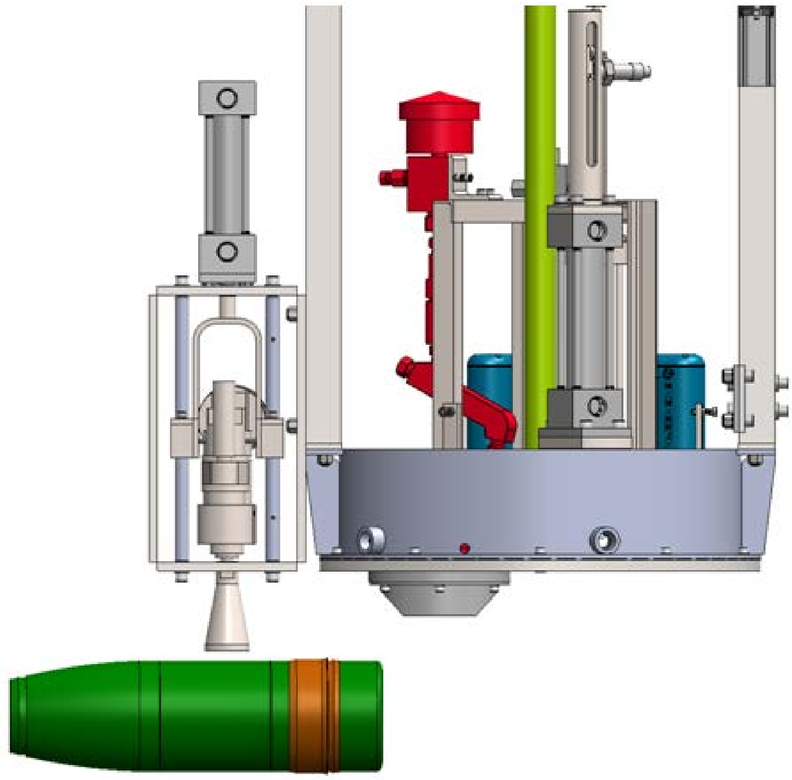

Figure 21. Cleaning head in position to clean the target item.

Figure 22. Cleaning head showing the five orifice positions.

The high-pressure water fed to the cleaning head will be at maximum pressure. The KMT Streamline SL-VI 100 *hp* waterjet intensifier pump to be used for this demonstration has a maximum operating pressure of $60,000$ *psi* and a maximum water flow rate of 1.88 *gpm*. Since the size of the orifices used sets the flow rate of water at a given pressure, the five orifices used in the cleaning head have to be carefully selected. In addition, it is generally desired to have maximum jet power, i.e., use the maximum water flow rate available at the highest pressure available. There are two basic equations that are used to determine water flow rate and jet power:

$$\boxed{\dot{Q} = 21.3 \cdot d_2^2 \sqrt{p_{1,ga}}} \tag{3}$$

$$\boxed{P = 5.831 \times 10^{-4} \cdot \dot{Q} \cdot p_{1,ga}} \tag{4}$$

where $\dot{Q}$ is volumetric flow rate of water in *gpm*, d_2 is orifice diameter in *inches*, $p_{1,ga}$ is the water pressure immediately upstream of the orifice, and P is the power in *hp*. Tables 4 and 5 tabulate the flow rate of water and jet power as a function of orifice size and water pressure. Also, Appendix C graphically displays Equations 3 and 4.

Table 4. Water Flow Rate in *gpm* as a Function of Orifice Size and Water Pressure

Orifice Size *inches*	Pressure in *ksi*										
	40	42	44	46	48	50	52	54	56	58	60
0.003	0.038	0.039	0.040	0.041	0.042	0.043	0.044	0.045	0.045	0.046	0.047
0.004	0.068	0.070	0.071	0.073	0.075	0.076	0.078	0.079	0.081	0.082	0.083
0.005	0.107	0.109	0.112	0.114	0.117	0.119	0.121	0.124	0.126	0.128	0.130
0.006	0.153	0.157	0.161	0.164	0.168	0.171	0.175	0.178	0.181	0.185	0.188
0.007	0.209	0.214	0.219	0.224	0.229	0.233	0.238	0.243	0.247	0.251	0.256
0.008	0.273	0.279	0.286	0.292	0.299	0.305	0.311	0.317	0.323	0.328	0.334
0.009	0.345	0.354	0.362	0.370	0.378	0.386	0.393	0.401	0.408	0.416	0.423
0.010	0.426	0.437	0.447	0.457	0.467	0.476	0.486	0.495	0.504	0.513	0.522
0.011	0.515	0.528	0.541	0.553	0.565	0.576	0.588	0.599	0.610	0.621	0.631
0.012	0.613	0.629	0.643	0.658	0.672	0.686	0.699	0.713	0.726	0.739	0.751
0.013	0.720	0.738	0.755	0.772	0.789	0.805	0.821	0.836	0.852	0.867	0.882
0.014	0.835	0.856	0.876	0.895	0.915	0.934	0.952	0.970	0.988	1.005	1.023
0.015	0.959	0.982	1.005	1.028	1.050	1.072	1.093	1.114	1.134	1.154	1.174
0.016	1.091	1.117	1.144	1.169	1.195	1.219	1.243	1.267	1.290	1.313	1.336
0.017	1.231	1.262	1.291	1.320	1.349	1.376	1.404	1.430	1.457	1.482	1.508
0.018	1.380	1.414	1.448	1.480	1.512	1.543	1.574	1.604	1.633	1.662	1.690
0.019	1.538	1.576	1.613	1.649	1.685	1.719	1.753	1.787	1.820	1.852	1.883
0.020	1.704	1.746	1.787	1.827	1.867	1.905	1.943	1.980	2.016	2.052	2.087

Table 5. Waterjet Power in hp as a Function of Orifice Size and Water Pressure

Orifice Size *inches*	Pressure in ksi										
	40	42	44	46	48	50	52	54	56	58	60
0.003	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6
0.004	1.6	1.7	1.8	2.0	2.1	2.2	2.4	2.5	2.6	2.8	2.9
0.005	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.6
0.006	3.6	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.6
0.007	4.9	5.2	5.6	6.0	6.4	6.8	7.2	7.6	8.1	8.5	8.9
0.008	6.4	6.8	7.3	7.8	8.4	8.9	9.4	10.0	10.5	11.1	11.7
0.009	8.0	8.7	9.3	9.9	10.6	11.2	11.9	12.6	13.3	14.1	14.8
0.010	9.9	10.7	11.5	12.3	13.1	13.9	14.7	15.6	16.5	17.3	18.3
0.011	12.0	12.9	13.9	14.8	15.8	16.8	17.8	18.9	19.9	21.0	22.1
0.012	14.3	15.4	16.5	17.6	18.8	20.0	21.2	22.4	23.7	25.0	26.3
0.013	16.8	18.1	19.4	20.7	22.1	23.5	24.9	26.3	27.8	29.3	30.8
0.014	19.5	21.0	22.5	24.0	25.6	27.2	28.9	30.5	32.3	34.0	35.8
0.015	22.4	24.1	25.8	27.6	29.4	31.2	33.1	35.1	37.0	39.0	41.1
0.016	25.4	27.4	29.3	31.4	33.4	35.5	37.7	39.9	42.1	44.4	46.7
0.017	28.7	30.9	33.1	35.4	37.7	40.1	42.6	45.0	47.6	50.1	52.8
0.018	32.2	34.6	37.1	39.7	42.3	45.0	47.7	50.5	53.3	56.2	59.1
0.019	35.9	38.6	41.4	44.2	47.2	50.1	53.2	56.3	59.4	62.6	65.9
0.020	39.7	42.8	45.9	49.0	52.2	55.5	58.9	62.3	65.8	69.4	73.0

Although the waterjet intensifier pump has a maximum operating pressure of $60,000$ psi, there is significant pressure drop through the piping that leads to the cleaning head (or similarly to the cutting head and washout head). Efforts are made to minimize the observed pressure drop but nonetheless the pressure drop must be accounted for when selecting an orifice. At this point, it is estimated that the pressure at the cleaning head will be $45,000$ psi. There is a pressure transmitter located upstream of all three tools that utilize high-pressure water so that the pressure can be measured. This transmitter is located in the high-pressure piping network before the high-pressure line splits to the three tools. Thus, the pressure immediately before a given tool is not measured. However, there is a flow meter on the water inlet to the waterjet intensifier pump that can be used to indirectly measure the upstream pressure of a given tool; Equation 3 is simply used to solve for $p_{1,ga}$.

Currently, the cleaning head will utilize five 0.008 *in* orifices which corresponds to a total water flow rate of 1.46 *gpm* and 37.9 *hp* for water at $45,000$ psi. However, during testing, the orifice size may be increased if additional jet power is required to adequately remove the bioencrustations in a timely manner.

After the bioencrustations are removed, the gantry is used to move the tool package in position for cutting. Figure 23 shows the tool package with the cutting head in position above the target item. The cutting head will utilize a 0.020 *in* orifice which corresponds to a water flow rate of 1.81 *gpm* and 47.4 *hp* for water at $45,000$ psi. After the cut is complete, the plug removal tool is lowered to the plug and then retracted to remove it. Figure 24 shows the tool package with the plug removal tool after removing the plug.

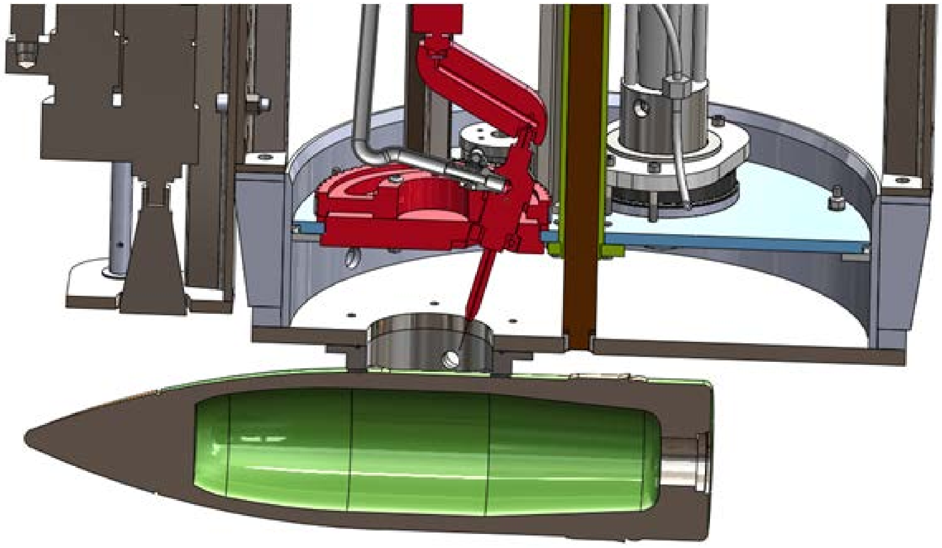

Figure 23. Cutting head in position to cut an access hole into the target item.

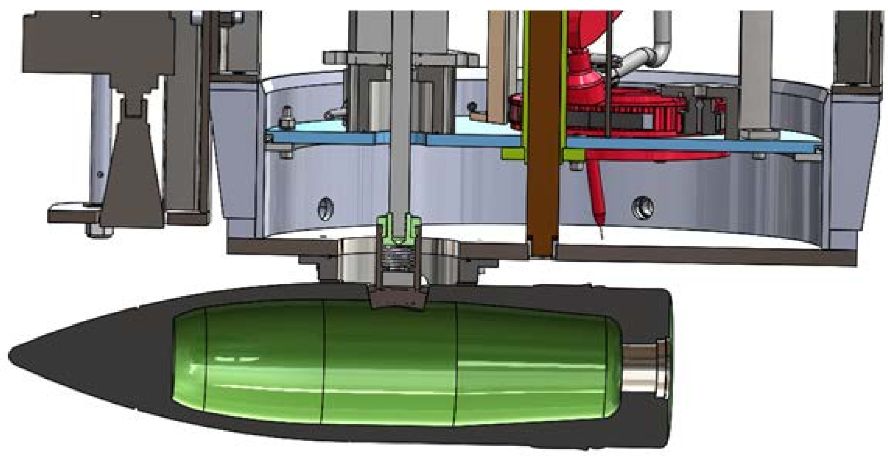

Figure 24. Plug removal tool in position to remove the cut plug.

After the plug is removed, the washout of the inert fill commences. The washout head allows for three orifices to be used and are arranged at specific angles so as to maximize jet coverage within the target item cavity. A variety of orifice sizes can be used as long as the total flow rate of water does not exceed the waterjet intensifier pump capacity. The selection of orifices used will potentially be varied during the demonstration depending upon the washout effectiveness. If the maximum pump capacity (1.88 gpm) is utilized and the pressure at the washout head is assumed to be $45,000$ psi, then the sets of orifices shown in Table 6 could be used as they all deliver the maximum pump capacity.

Table 6. Orifice Configurations for the Washout Head that Deliver 1.88 *gpm* at 45,000 *psi*

Orifice Sizes in *inches*		
1	2	3
0.003	0.003	0.020
0.003	0.009	0.018
0.004	0.012	0.016
0.005	0.010	0.017
0.005	0.014	0.014
0.007	0.012	0.015
0.007	0.013	0.014
0.008	0.008	0.017
0.009	0.009	0.016
0.010	0.011	0.014

Figure 25 shows a typical multi-orifice washout head. The washout head is slowly and controllably inserted into the target item cavity and then retracted to wash out the inert fill. During the demonstration, the insertion and retraction rate will be varied so as to maximize the removal of the inert fill. Figure 26 shows the tool package with the washout head inserted into the target item.

Figure 25. Typical multi-orifice washout head for removing material from a cavity.

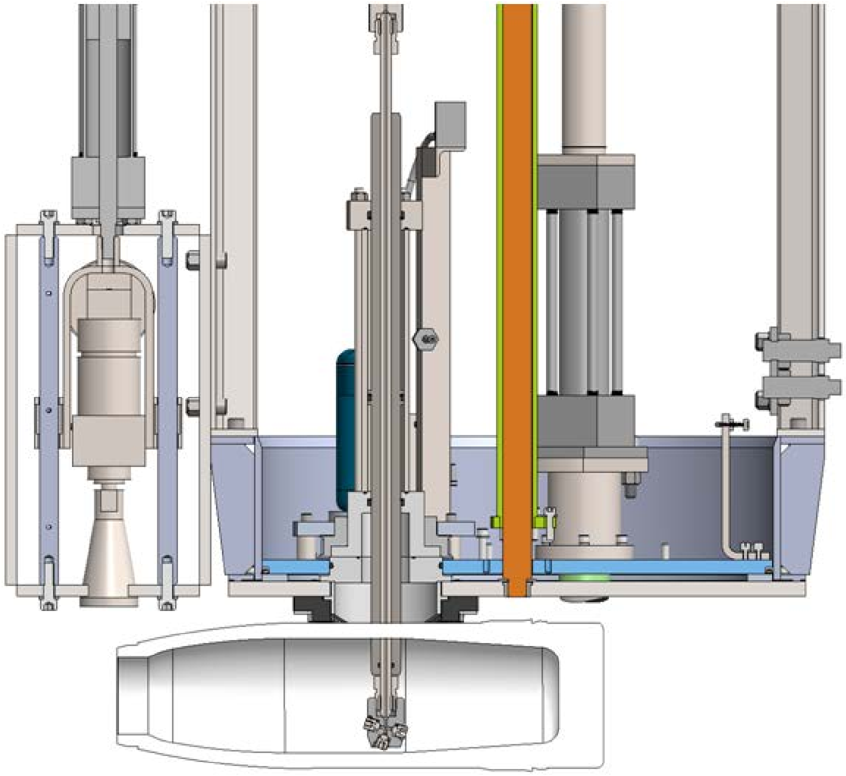

Figure 26. Washout head inserted into the target item.

5.6 Operational Procedure

The procedure used to process an inert target item placed on the floor is detailed in this section. This procedure is divided into four major operations:

1. Pre-operational tasks
2. Tool package deployment with the gantry crane
3. Inert target item processing
4. Tool package retrieval with the gantry crane

Pre-operational tasks include the placement of an inert item on the floor off of the pier as well as retrieval of the item after processing. NSA-Panama City divers will be used to place/retrieve these items and they will adhere to their operational procedures and safety plans. NSA-Panama City personnel will also utilize their operational procedures and safety plans for deploying and retrieving the tool package into the water off of the pier where the inert test item is located. Lastly, Delta SubSea personnel are trained to use the sonar imaging hardware and will be responsible for its operation.

The pre-operational tasks include the execution of the following steps after the target item has been placed on the floor:

1. Start the electrical generator.
2. Turn on feed water to the feed water tank.
3. Turn on the feed water pump.
4. Turn on compressed air to the system.
5. Ensure main high-pressure block valve is closed.
6. Start the high-pressure intensifier pump and allow the hydraulics to warm up.
7. Pressurize the high-pressure network and inspect for leaks. De-pressurize when complete.
8. Pressurize the abrasive hopper.
9. Confirm the control system is communicating properly to the HMI.
10. Confirm all operational parameters are properly set on the control system
11. Confirm all cameras are functional.
12. Confirm the sonar imaging hardware is functional.
13. Inspect and ensure the capture network is functional and that the collection tote can receive captured material.
14. Turn on hydraulic unit.
15. Raise the turntable on the tool package.
16. Rotate the cutting head to its starting position.
17. Turn on the DVR.

The tool package deployment with the gantry crane tasks include the execution of the following steps:

1. NSA-Panama City personnel will deploy the tool package with their pier-side crane over the top of the inert target item.
2. Confirm all cameras are functional.
3. Confirm the sonar imaging hardware is functional.
4. Confirm the umbilical of instrument cables, hydraulic lines, pneumatic lines, high-pressure line, and abrasive line is properly routed to all support equipment on the pier.

Inert target item processing tasks include the execution of the following steps:

1. Turn on hydraulic unit.

2. Turn on the high-pressure intensifier pump.
3. Pressurize the high-pressure network.
4. Use gantry controls to mate the tool to the inert target item.
5. Ensure turntable is in cutting position.
6. Lower turntable to cutting position.
7. Open capture network discharge valve.
8. Start capture pumps.
9. After pumps are primed, execute the cutting sequence.
10. After cutting sequence is executed, stop the capture pumps.
11. Raise turntable.
12. Rotate the cutting head back to its proper start position.
13. Rotate turntable to magnet position.
14. Lower magnet and remove plug.
15. Rotate the turntable to the wash position.
16. Start capture pumps.
17. After pumps are primed, execute the wash sequence.
18. After wash sequence is executed, stop the capture pumps.
19. Rotate the turntable to the magnet position.
20. Turn off the hydraulic unit.
21. Turn off the high-pressure intensifier pump and de-pressurize the network.

The tool package retrieval with the gantry crane tasks include the execution of the following steps:

1. NSA-Panama City personnel will retrieve the tool package with their pier-side crane.
2. Turn on hydraulic unit.
3. Retract magnet to drop plug.
4. Turn off hydraulic unit.
5. Rotate the turntable to cutting position.

5.7 Calibration Activities

The primary equipment pieces requiring calibration are the abrasive feeder and servo motors. This equipment will be calibrated prior to test plan execution so that proper and accurate control can be implemented. Figure 27 shows a typical calibration curve for the abrasive feeder in which the delivered abrasive mass flow rate is plotted versus the abrasive feeder speed setpoint and fit to a second-degree polynomial.

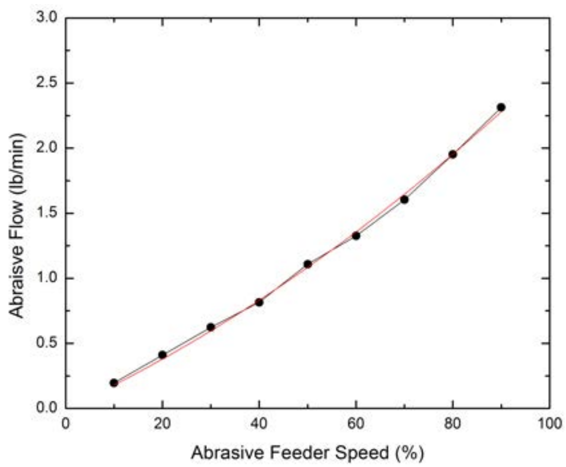

Figure 27. Typical abrasive feeder calibration curve.

5.8 Data Collection Procedures

Data collection for this demonstration starts with the quantification of the masses of the prepared target items. Gradient Technology will load inert munitions with microcrystalline cellulose to simulate the energetic fill. This material will be loaded incrementally into the item using a hydraulic press. The mass of the initial empty item and loaded microcrystalline cellulose will be recorded. Subsequent masses of the processed items will be recorded as specified in Section 3.

Demonstration operations will be recorded with cameras since a great deal of visual information can be ascertained from the operations. This data will be collected, assessed, and archived for reference. The sonar imaging data will be recorded, assessed, and archived for reference. During daily operations, all observations are continuously documented in a laboratory notebook to facilitate the creation of the demonstration report.

5.9 Validation

The technology demonstrated during this testing phase will be validated upon successful comparison to the objective criteria previously discussed.

6 Data Analysis Plan

All data, both quantitative and qualitative, will be analyzed during and after demonstration plan execution. Real time data analysis will be used to modify and direct subsequent testing. Post-testing analysis results will be incorporated into the subsequent final report.

6.1 Preprocessing

The data collected during this demonstration does not require any preprocessing. All measurements are direct and can be used to calculate desired metrics.

6.2 Target Selection For Detection

All targets will be inert and prepared prior to the demonstration. Detection of items is not a part of the scope of this demonstration.

6.3 Parameter Estimation

All parameters required in the demonstration have been estimated and are based on the twenty years of operational experience Gradient Technology has acquired during the execution of demilitarization utilizing high-pressure waterjets.

6.4 Data Product Specification

The data, results, and conclusions of demonstration will be detailed in the final report that will be prepared during Task 8 of this project.

7 Cost Assessment

This is not applicable as the Government will not be acquiring this technology.

8 Schedule of Activities

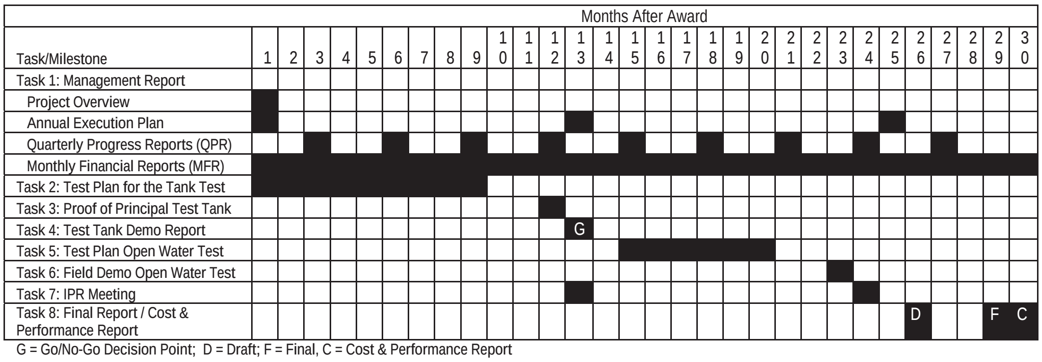

Figure 28. Schedule of activities for this project in which month 1 is September 2018. The open water demonstration (Task 6) will occur in June 2020.

9 Management and Staffing

The relationship between the organizations involved is summarized in the flow chart shown in Figure 29.

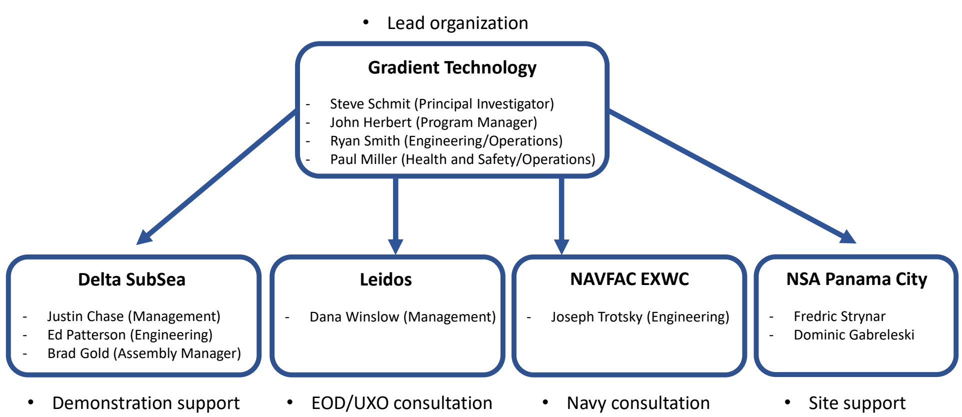

Figure 29. Project organization flow chart.

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Appendix A

Health and Safety Plan (HASP)

This Health and Safety Plan exists to provide information in regards to health and safety of employees and visitors of Gradient Technology. This plan will outline site-specific hazards, procedures, contact information, and plans for reducing the severity of or eliminating any hazards. Note that this document is site specific and is not intended to be a generic safety document for other locations or projects.

A.1 Worksite Location Details

The worksite is adjacent to the pier, Bldg 582, NSA Panama City, Florida.

A.2 General Work Description

Gradient Technology and Delta SubSea will conduct a demonstration of integrated equipment for the demilitarization of underwater munitions in an open water environment. Gradient Technology and Delta SubSea personnel will conduct the demonstration.

A.3 Primary Site Contact

NSA Panama City POC:
Fredric Strynar: 850-399-0312
Dominic Gabreleski: 850-628-6626

Gradient Technology POC:
John Herbert: 757-377-7144 (cell)
Steve Schmit: 612-812-1669 (cell)
Ryan Smith: 612-325-8093 (cell)

A.4 Emergency Services Information/Contact

The nearest emergency room is located 7.3 miles away at Gulf Coast Regional Medical Center (449 W 23rd St, Panama City, FL 32405) as shown in Figure A30. Dial 911 in an emergency.

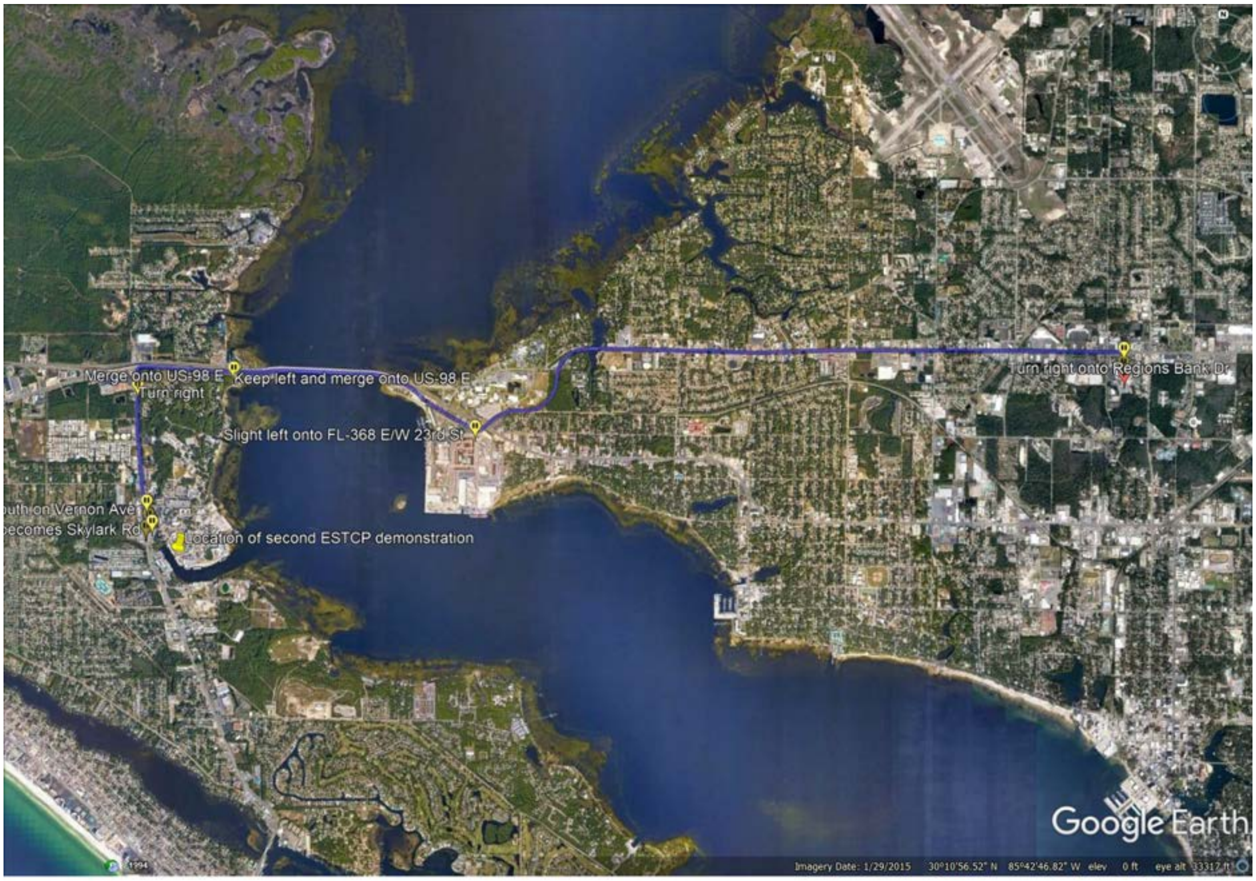

Figure A30. Location of Gulf Coast Regional Medical Center with respect to the demonstration site.

A.5 Accident/Incident Contact

NSA Panama City POC:
Fredric Strynar: 850-399-0312
Dominic Gabreleski: 850-628-6626

Gradient Technology POC:
John Herbert: 757-377-7144 (cell)
Steve Schmit: 612-812-1669 (cell)
Ryan Smith: 612-325-8093 (cell)

A.6 Project Specific Hazards

- Compressed air lines
- Hydraulic lines
- High-pressure water lines
- Slips, trips, and falls

  - Buddy sytem.
  - Personnel will look for and identify pre-existing slip, trip, and fall hazards.
  - The work area will be cleared of all unnecessary materials and equipment that could create slip, trip, or fall hazards prior to beginning work.
  - If feasible, walking or working surfaces will be improved to eliminate uneven conditions. If it is not feasible to improve this condition, then uneven surfaces will be identified, communicated, and/or marked to warn employees of the hazard.

- Equipment set up
  - Gradient Technology authorizes only those employees qualified by training or previous experience to locate and place either the fixtures or high-pressure waterjet equipment.
  - Equipment must be checked at the beginning of each shift to ensure the equipment is in safe operating condition and free of apparent damage. All defects shall be corrected before the equipment is placed in service. Documentation of this inspection must be maintained onsite at all times.
  - Equipment must be on a stable foundation such as solid ground or cribbing; outriggers are to be fully extended.
  - Operators loading/unloading from vehicles are responsible for seeing that vehicle drivers are in the vehicle cab or in a safe area.
  - When not in operation, the high-pressure waterjet system shall be shut down and the water side depressurized. When equipment is unattended, power must be shut off, depressurized, and locked out.

- Lockout/Tagout activities
  - Only qualified personnel may work on energized equipment that has not been de-energized by lockout/tagout procedures.
  - When Gradient Technology personnel are affected by the unexpected operation of equipment, they must complete the lockout/tagout training course in the Basic Program. Project training may also be required on site specific lockout procedures.
  - Standard lockout/tagout procedures include the following six steps: 1) notify all personnel in the affected area of the lockout/tagout, 2) shut down the equipment using normal operating controls, 3) isolate all energy sources, 4) apply individual lock and tag to each energy isolating device, 5) relieve or restrain all potentially hazardous stored or residual energy, and 6) verify that isolation and de-energization of the equipment has been accomplished. Once verified that the equipment is at the zero-energy state, work may begin.
  - All safe guards must be put back in place, all affected personnel notified that lockout has been removed and controls positioned in the safe mode prior to lockout removal. Only the individual who applied the lock and tag may remove them.

- Refer to Gradient Technology SOP "Lockout and Tagout" for more specific details on lockout/tagout requirements.

- Vehicular traffic
  - Exercise caution when exiting traveled way or parking along street – avoid sudden stops, use flashers, etc.
  - Park in a manner that will allow for safe exit from vehicle, and where practicable, park vehicle so that it can serve as a barrier.
  - All staff working adjacent to traveled way or within work area must wear reflective/high-visibility safety vests.
  - Eye protection should be worn to protect from flying debris.
  - Remain aware of factors that influence traffic related hazards and required controls – sun glare, rain, wind, flash flooding, limited sight-distance, hills, curves, guardrails, width of shoulder (i.e., breakdown lane), etc.
  - Always remain aware of an escape route – behind an established barrier, parked vehicle, guardrail, etc.
  - Always pay attention to moving traffic – never assume drivers are looking out for you.
  - Work as far from traveled way as possible to avoid creating confusion for drivers.

- Overhead hazards
  - Hard hat must be worn anytime an individual is within the arc of the pier gantry crane.
  - Individuals not directly involved in crane operations will remain clear of the area while lifting of the underwater gantry is taking place.
  - Area around gantry crane and between underwater gantry and the water must remain clear of all obstacles and trip hazards.

- Lifting
  - Proper lifting techniques must be used when lifting any object.
  - Plan storage and staging to minimize lifting or carrying distances.
  - Split heavy loads into smaller loads.
  - Use mechanical lifting aids whenever possible.
  - Have someone assist with the lift – especially for heavy or awkward loads.
  - Make sure the path of travel is clear prior to the lift.

- Fire prevention
  - Fire extinguishers shall be provided so that the travel distance from any work area to the nearest extinguisher is less than 100 feet. When 5 gallons or more of a flammable or combustible liquid is being used, an extinguisher must be within 50 feet. Extinguishers must be maintained in a fully charged and operable condition, be visually inspected each month, and undergo a maintenance check each year.

  - The area in front of extinguishers must be kept clear.
  - Post "Fire Extinguisher" signs over extinguisher locations.
  - Combustible materials stored outside should be at least 10 feet from any building.
  - Solvent waste and oily rags must be kept in a fire resistant, covered container until removed from the site.
  - Flammable/combustible liquids must be kept in approved containers, and must be stored in an approved storage cabinet.

- Electrical
  - Only qualified personnel are permitted to work on unprotected energized electrical systems.
  - Only authorized personnel are permitted to enter high-voltage areas.
  - Do not tamper with electrical wiring and equipment unless qualified to do so. All electrical wiring and equipment must be considered energized until lockout/tagout procedures are implemented.
  - Inspect electrical equipment, power tools, and extension cords for damage prior to use. Do not use defective electrical equipment, remove from service.
  - All temporary wiring, including extension cords and electrical power tools, must have ground fault circuit interrupters (GFCIs) installed.
  - Extension cords must be equipped with third-wire grounding, covered, elevated, or protected from damage when passing through work areas, protected from pinching if routed through doorways, and not fastened with staples, hung from nails, or suspended with wire.
  - Electrical power tools and equipment must be effectively grounded or double-insulated UL approved.
  - Operate and maintain electric power tools and equipment according to manufacturers' instructions.
  - Temporary lights shall not be suspended by their electric cord unless designed for suspension. Lights shall be protected from accidental contact or breakage.
  - Protect all electrical equipment, tools, switches, and outlets from environmental elements.

- Severe weather
  - Verify weather conditions before beginning operations. Suspend work if lightning within 50 miles of site. Shelter from the first sign of lightning until 30 minutes after last sign.
  - Locate the nearest severe weather shelter and strong structure prior to initiating work each day should immediate cover be needed.
  - Do not work if heavy rain or severe wind is forecast in immediate area.

- Heat stress

– Drink 16 ounces of water before beginning work. Bottled water maintained at 50^oF to 60^oF should be available. Under severe conditions, drink 1 to 2 bottles every 20 minutes, for a total of 1 to 2 gallons per day. Do not use alcohol in place of water or other nonalcoholic fluids. Decrease your intake of coffee and caffeinated soft drinks during working hours.

– Acclimate yourself by slowly increasing workloads (e.g., do not begin with extremely demanding activities).

– Avoid direct sun whenever possible, which can decrease physical efficiency and increase the probability of heat stress. Take regular breaks in a cool, shaded area. Use a wide-brim hat or an umbrella when working under direct sun for extended periods.

– Provide adequate shelter/shade to protect personnel against radiant heat (sun, flames, hot metal).

– Maintain good hygiene standards by frequently changing clothing and showering.

– Observe one another for signs of heat stress. Persons who experience signs of heat syncope, heat rash, or heat cramps should consult the site lead to avoid progression of heat-related illness.

SYMPTOMS AND TREATMENT OF HEAT STRESS

	Heat Syncope	**Heat Rash**	**Heat Cramps**	**Heat Exhaustion**	**Heat Stroke**
Signs and Symptoms	Sluggishness or fainting while standing erect or immobile in heat.	Profuse tiny raised red blister-like vesicles on affected areas, along with prickling sensations during heat exposure.	Painful spasms in muscles used during work (arms, legs, or abdomen); onset during or after work hours.	Fatigue, nausea, headache, giddiness; skin clammy and moist; complexion pale, muddy, or flushed; may faint on standing; rapid thready pulse and low blood pressure; oral temperature normal or low.	Red, hot, dry skin; dizziness; confusion; rapid breathing and pulse; high oral temperature.
Treatment	Remove to cooler area. Rest lying down. Increase fluid intake. Recovery usually is prompt and complete.	Use mild drying lotions and powders, and keep skin clean for drying skin and preventing infection.	Remove to cooler area. Rest lying down. Increase fluid intake.	Remove to cooler area. Rest lying down, with head in low position. Administer fluids by mouth. Seek medical attention.	Cool rapidly by soaking in cool–but not cold–water. Call ambulance, and get medical attention immediately!

- Sun exposure

  – Wide brimmed hats are recommended

  - Sun screen of at least SPF 40 is recommended
  - Cover exposed skin by wearing light weight clothing to include long sleeved shirts and long pants.

A.7 General PPE Requirements

- Safety glasses
- Safety shoes
- Hard hat
- Work gloves required if handling pipes, tools, etc.

A.8 Job Specific PPE Requirements

The general PPE requirements of section A.7 are sufficient.

A.9 Special Training Requirements

Training on the use of the high-pressure pump and associated hazards of high-pressure water will be administered by Gradient Technology to the Delta SubSea personnel involved with the demonstration.

A.10 Housekeeping/Decontamination Requirements

Since only inert target items are being processed, there are no decontamination requirements. There will be equipment located in different areas of the site that are interconnected with cables and pipes. Therefore, all areas need to be properly marked and/or barricaded and kept organized to avoid tripping hazards and prevent vehicles such as forklifts, cranes, and trucks from driving over these lines.

A.11 Specific NSA Panama City Site Instructions

Base access is through the main gate off of Thomas Drive. Personnel entering must have a CAC card, military ID, or have filled out the SECNAV 5512 base access security registration form at least two weeks prior to the visit.

A.12 Hand/Power Tool Limitations

None at this time.

A.13 Environmental Reporting

None at this time.

Appendix B

Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax Email	Role in Project
John Herbert	Gradient Technology	P: 763-792-9990 F: 763-792-9972 herbert@gradtech.com	Program Manager
Steve Schmit	Gradient Technology	P: 763-792-9990 F: 763-792-9972 schmit@gradtech.com	Lead Principal Investigator
Ryan Smith	Gradient Technology	P: 763-792-9990 F: 763-792-9972 smith@gradtech.com	Engineering/Operations
Paul Miller	Gradient Technology	P: 763-792-9990 F: 763-792-9972 miller@gradtech.com	Health and Safety/Operations

Appendix C

High-pressure Waterjet Orifice Size, Flow Rate, and Power Diagram

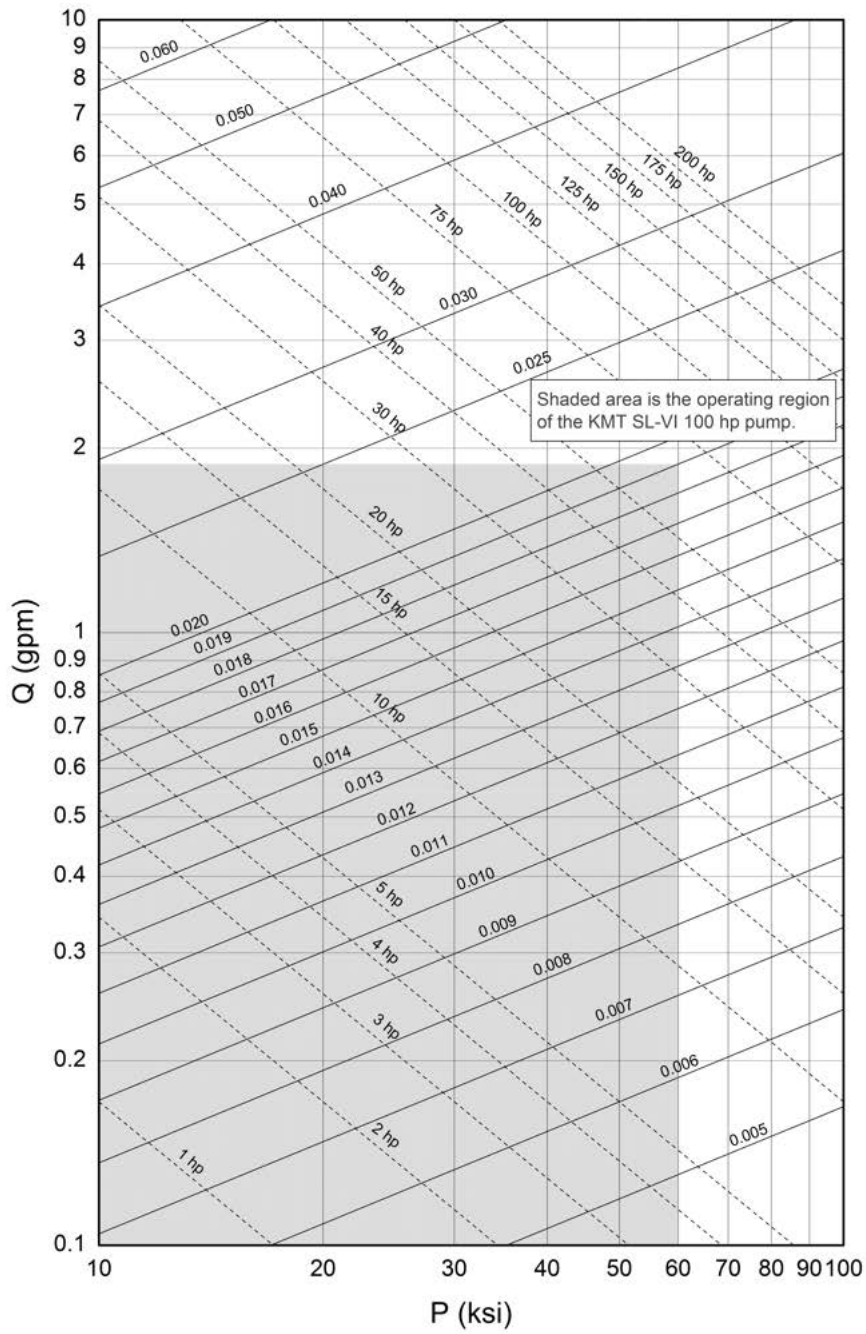

Figure C31. Relationship between orifice size, water flow rate, and power for high-pressure waterjets.