NATURE OF DISCHARGE REPORT

Underwater Ship Husbandry

1.0 INTRODUCTION

The National Defense Authorization Act of 1996 amended Section 312 of the Federal Water Pollution Control Act (also known as the Clean Water Act (CWA)) to require that the Secretary of Defense and the Administrator of the Environmental Protection Agency (EPA) develop uniform national discharge standards (UNDS) for vessels of the Armed Forces for "...discharges, other than sewage, incidental to normal operation of a vessel of the Armed Forces, ..." [Section 312(n)(1)]. UNDS is being developed in three phases. The first phase (which this report supports), will determine which discharges will be required to be controlled by marine pollution control devices (MPCDs)—either equipment or management practices. The second phase will develop MPCD performance standards. The final phase will determine the design, construction, installation, and use of MPCDs.

A nature of discharge (NOD) report has been prepared for each of the discharges that has been identified as a candidate for regulation under UNDS. The NOD reports were developed based on information obtained from the technical community within the Navy and other branches of the Armed Forces with vessels potentially subject to UNDS, from information available in existing technical reports and documentation, and, when required, from data obtained from discharge samples that were collected under the UNDS program.

The purpose of the NOD report is to describe the discharge in detail, including the system that produces the discharge, the equipment involved, the constituents released to the environment, and the current practice, if any, to prevent or minimize environmental effects. Where existing process information is insufficient to characterize the discharge, the NOD report provides the results of additional sampling or other data gathered on the discharge. Based on the above information, the NOD report describes how the estimated constituent concentrations and mass loading to the environment were determined. Finally, the NOD report assesses the potential for environmental effect. The NOD report contains sections on: Discharge Description, Discharge Characteristics, Nature of Discharge Analysis, Conclusions, and Data Sources and References.

2.0 DISCHARGE DESCRIPTION

This section describes the underwater ship husbandry discharge and includes information on: the equipment that is used and its operation (Section 2.1), the general description of the constituents of the discharge (Section 2.2), and the vessels that produce this discharge (Section 2.3).

2.1 Equipment Description and Operation

For the purpose of this evaluation, underwater ship husbandry is defined as the inspection, grooming, maintenance, and repair of hulls and hull appendages performed while a vessel is waterborne. In the case of repairs, they may be classified as permanent (equivalent to dry-dock repair); temporary (to be reworked at the next scheduled dry-docking); and emergency (allowing the ship to transit to a facility for further repair). Underwater ship husbandry includes the following operations:[1,2]

- hull cleaning,
- fiberglass repair,
- welding,
- sonar dome repair,
- non-destructive test/inspection,
- masker belt repairs, and
- paint operations, and
- SEAWOLF propulsor layup.

All of these activities are typically conducted while ships are pierside. Cleaning of underwater hulls is the major activity within this category, and is performed on a routine basis.[1] Layup of SEAWOLF propulsors occurs approximately 6 times per year.[3] The remaining operations are unplanned repair activities incidental to normal vessel operation.[1]

2.1.1 Underwater Hull Cleaning

Underwater hull cleaning is performed to remove fouling organisms which have adhered to a vessel and its appendages.[4] Biological growth is undesirable since it increases ship drag, thereby increasing fuel consumption and decreasing speed. Hull cleanings can be either full cleanings or interim cleanings. Full cleanings are those which include the entire painted underwater hull surface, propellers, and propeller shafts. Interim cleanings include the cleaning of propellers and shafts only.

Hull Coating Systems. Ablative hull coating systems are typically comprised of two coats (layers) of epoxy anticorrosion (AC) paint applied to the bare hull and two coats of copper antifouling (AF) paint applied over the AC coating. The function of the AC coat, in conjunction with cathodic protection, is to prevent hull corrosion. The AC coat also provides bonding between the hull and the AF topcoats. AF topcoats control biological growth by ablating and/or leaching antifouling agents into the surrounding water (as described in the Hull Coating Leachate

NOD report). The total design thickness of this system is 20 mils (1 mil = 0.001 inches), of which 10 mils are the AF coating, although the actual application may be thicker.[5]

Most ships of the Navy, Military Sealift Command (MSC), and U.S. Coast Guard (USCG) use AF paint qualified to MIL-PRF-24647 "Paint System, Anticorrosive and Antifouling, Ship Hull."[6,7] While several types of AF topcoats conform to this specification, the most common types are ablative, copper-based coatings.[8] An ablative coating thins as it erodes or dissolves. Through this action, a fresh layer of antifouling agent (e.g. copper) is exposed, maintaining the paint's antifouling properties. Self-polishing AF paints are a type of ablative coating which undergoes chemical hydrolysis when it comes into contact with the slightly alkaline seawater. Any toxic agents which are chemically bound to the paint matrix will be released at a rate dependent upon the rate of hydrolysis.

Other vessels of the Armed Forces use non-ablative paint systems which do not appreciably diminish in thickness during service.[7] Non-ablative paints containing tributyltin (TBT) are still found on some aluminum-hulled small craft because some copper-based paints are incompatible with aluminum hulls.[8] However, TBT paints are no longer approved for any Navy vessel, including aluminum-hulled craft, effective as of fiscal year (FY) 1998.[5,9]

Coating Service Life. Ablative copper AF coatings for naval vessels are designed to meet five-, seven-, or ten-year dry-docking periods.[9] Typically, ablative copper AF coatings remain free of fouling for about three years after application before they require in-water hull cleaning.[10] After the first cleaning, they typically require an annual hull cleaning, which is usually performed just prior to deployments, to optimize fuel consumption underway. This is only a guideline, since the frequency of cleaning is also influenced by the ship's schedule and location.[4]

Inspection and Evaluation. Navy vessels are inspected quarterly and before deployments, and are assigned a Fouling Rating (FR) on a scale of 0 to 100.[1,4] This rating is established by comparing photographs of the fouled hull with photographic standards representing values on the FR scale. The criteria for performing hull cleaning is FR 40 or higher (for ablative and self-polishing paint systems) over 20% of the ship's hull; or the presence of FR 50 or higher (for non-ablative paint systems) over 10% of the ship's hull.[4]

Underwater Hull Cleaning Process. Underwater hull cleaning can be accomplished with hand-held rotary brush units, self-propelled multi-brush cleaning vehicles, water jets, and hand-held scrapers.[4] Most often, it is conducted by divers using the Submerged Cleaning and Maintenance Platform (SCAMP) or the similar SeaKlean multi-brush systems.[1] These mechanical devices are held next to the hull from the thrust and suction generated by a large impeller, which pumps seawater at approximately 13,500 gallons per minute (gpm). While the brushes rotate and sweep biofouling off of the hull, the system moves forward at a maximum rate of 1 foot per second (ft/sec), but typically at 0.75 ft/sec. A small percentage of the hull, gratings, and struts; which are inaccessible to these multi-brush machines, must be cleaned using hand-held single-brush cleaning units.[10]

2.1.2 Other Underwater Repair, Maintenance, And Inspection Processes

Fiberglass Repair. Two activities comprise this class of ship husbandry: fiberglass hull repairs and fiberglass propeller shaft coating repairs. Methods for performing underwater fiberglass hull repairs are still under development, and therefore are not a standard operation. Shafts are coated with fiberglass to prevent corrosion. A confirmed or suspected failure in the fiberglass coating may require an underwater repair, if dry-docking is not imminent.[1]

Fiberglass shaft repairs are performed by divers working in a dry underwater enclosure, or "habitat," having an opening in the underside for diver access.[11] When coating shafts with fiberglass, glass reinforced plastic (GRP) wrapping is applied in accordance with MIL-STD-2199, "Glass Reinforced Plastic Coverings for Propeller Shafting." In this procedure, the shaft is first cleaned with a solvent, typically acetone, to remove grease and oil. Next, four wrappings of fiberglass tape/cloth are made and fixed with a viscous epoxy or polyester resin which hardens into an insoluble plastic. The cure time and working life of the resin vary with the individual brand, temperature, and humidity. However, the total cure time is on the order of 24 hours. The working life of the resin, after the addition of the hardener, is significantly less. The specification states that resin systems may have a working life from 30 minutes to six hours at 73 °F and as short as 18 minutes at 90 °F. The specification recommends that a new resin pot be prepared for each wrapping, because it may harden between wrapping passes.[12]

Welding. There are two types of underwater welding: dry habitat and wet welding. An underwater enclosure is used for dry habitat welding, the use of which is required for slower cooling of high strength steels. A high-flow air system filters and exhausts the welding fumes and provides a safe atmosphere for the welder. In wet welding, operations are performed under submerged conditions. Specially coated welding rods allow the flux to bond with the wet surface. Before welding, the area is cleaned with scrapers, chipping hammers, or hand-held brushes.[11,13]

Sonar Dome Repair. Minor repairs to the exterior of rubber sonar domes can be accomplished by divers. The most common repair is patching the rubber window. A diver removes loose rubber, prepares the edges to receive a patch, and affixes a rubber patch with an amine polymer.[11]

Non-Destructive Test/Inspection. Underwater magnetic particle testing is used as a non-destructive inspection method to detect or define surface or near-surface cracks in ferrous metal structures prior to repair. It may also be used for welding quality assurance. An electromagnet is used to magnetize a localized area on the hull surface. A slurry of fluorescent iron flakes is then applied to the weld or crack with a squeeze bottle. These particles align with the defective area, facilitating inspection.[11,14]

Masker Belt Repairs. Masker emitter belts are installed at the forward end of the ship's machinery spaces and run vertically down both sides of the external hull. The masker belt is a continuous length of copper-nickel pipe that emits air bubbles through small holes to mask ship noise. The pipe is epoxied into a fairing channel that is welded to the hull. The channel ensures that the hull shape remains "fair," or smoothly curved, so the masker belt does not protrude and increase drag. Waterborne repairs by divers consist of cutting away damaged belt sections and installing replacement sections. An insert is used to join the replacement with existing sections. Finally, an epoxy sealer is applied to ensure a positive air seal.[11]

Paint Operations. Underwater touchup painting is required after welding, shaft lamination repairs, and masker belt repairs. Touchup painting is also performed to repair paint damage or deterioration on surfaces such as rudders, dielectric shielding for the cathodic protection system, struts, and stern tubes. Epoxy paint is mixed on the surface (above water), supplied to the diver, and applied to the affected area with a brush or roller.[11]

SEAWOLF Propulsor Layup. The newly commissioned SEAWOLF attack submarine utilizes vinyl covers to prevent fouling of the propeller (also called propulsor) when it is in port for extended periods. The covers, referred to as the Propulsor Protective Covering System (PPCS), restrict sunlight and the supply of fresh nutrient-rich water into the propulsor. Reducing the amount of fouling that occurs on the propulsor in port reduces the need for underwater cleaning of the propulsor.[2]

2.2 Releases to the Environment

2.2.1 Underwater Hull Cleaning

Underwater hull cleaning is accomplished by divers operating hand-held rotary brush units, self-propelled multi-brush cleaning vehicles, water jets, and hand-held scrapers.[4] These tools sweep or dislodge biofouling from the wetted surface of the hull and appendages.[1] The discharge from the cleaning process consists of seawater (from the impeller of the cleaning vehicle), living and dead marine organisms, and antifouling paint.[10] Variables affecting the amount of this discharge include hull surface area, condition of the paint system, degree of fouling, brush selection, conditions in the water, and the skill of the operators.

2.2.2 Other Underwater Repair, Maintenance, And Inspection Processes

Fiberglass Repair. A two component system consisting of an epoxy resin and a hardener is mixed topside and transferred to the underwater habitat to accomplish the fiberglass repairs.[15] Due to the rapid curing time of the resin system, it is applied to the surface to be repaired soon after mixing, and then covered with glass tape. Releases of fiberglass and resin can occur when materials fall through the open bottom of the enclosure.[11] Since the resin being applied quickly solidifies, any releases from the enclosure will fall to the bottom of the harbor.

Welding. Small amounts of welding consumables can enter the marine environment upon entry into or exit from the dry welding habitat, or by passing directly into the water during wet welding.[11] Slag, which is molten refuse material from the welding process, may fall from the welding area into the water column. Some spent welding rods and welding gases may also be released.

Sonar Dome Repair. When the diver removes the loose rubber from the sonar dome and affixes a rubber patch with adhesive, a discharge of solid rubber waste and/or adhesive may result.[11]

Non-Destructive Test/Inspection. The slurry of iron flakes applied to the weld is discharged directly into the water column.[11]

Masker Belt Repairs. Waterborne repairs consist of cutting away damaged belt sections and installing replacement sections as described in Section 2.1.[11] Portions of the damaged belt or some of the epoxy sealer can be released during this operation.

Paint Operations. While a diver is performing underwater touchup painting with epoxy coatings, some paint can be incidentally released into the water in the vicinity of the painting operation.[11] Neither the epoxy resin nor the amine compound of the primary products in use are water-soluble.[16]

SEAWOLF Propulsor Layup. Use of the PPCS creates a relatively isolated volume of water of approximately 21,000 gallons inside the propulsor. The chemistry of this volume of water can change over time, primarily due to the generation of small amounts of chlorine from the installed Impressed Current Cathodic Protection (ICCP) system and the decay of trapped organic matter. (Descriptions of the purpose and function of ICCP systems can be found in the Cathodic Protection NOD report). Releases to the environment resulting from the layup of the propulsor include decaying organic matter, chlorine, and Chlorine Produced Oxidants (CPO). CPO is used to describe the combination of oxidant species that may, in this case, be formed by the ICCP system in both primary and secondary reactions, and includes various chlorinated and brominated species.[17]

2.3 Vessels Producing the Discharge

All Navy surface ships and submarines undergo periodic underwater ship husbandry.[1] However, the predominant discharge is from underwater hull cleanings. Underwater cleanings are performed on larger vessels between dry-docking periods. The Navy, with the greatest number of large vessels, produces this discharge more frequently than the other Armed Forces. The U.S. Coast Guard (USCG), Military Sealift Command (MSC), Army, and Air Force dry-dock their vessels more frequently, at which time hull cleaning is performed.[18, 19, 20] Small boats and craft are typically removed from the water for maintenance and repairs.[1] Layup of SEAWOLF Propulsors is currently limited to the SEAWOLF Class of attack submarines. The first of this class, SSN 21, was commissioned in the fall of 1997, with a total of 3 submarines planned. The next attack submarine class, commonly referred to as the “New Attack Submarine,” is also expected to use a PPCS type system.

3.0 DISCHARGE CHARACTERISTICS

This section contains qualitative and quantitative information that characterizes the discharge. Section 3.1 describes where the discharge occurs with respect to harbors and nearshore areas, Section 3.2 describes the rate of the discharge, Section 3.3 lists the constituents in the discharge, and Section 3.4 gives the concentrations of the constituents in the discharge.

3.1 Locality

Underwater ship husbandry is conducted pierside.[1]

3.2 Rate

Because of the variability in vessel surface area and in the volume of these releases for underwater ship husbandry, rates are discussed in terms of frequency of the event.

3.2.1 Underwater Hull Cleaning

On average, each Navy surface ship will receive five underwater hull cleanings every six years.[1] These statistics vary regionally depending on fouling rates, water temperatures, and the coating service life. Vessels in Pearl Harbor, HI, for example, would have higher fouling rates, and, therefore, a higher cleaning frequency than those in Norfolk, VA. An average of 136 full cleanings (including the hull surface, propeller, and shaft) are performed annually fleetwide, based on the following four years of data:[21]

1993: 131 vessels
1994: 131 vessels
1995: 135 vessels
1996: 148 vessels

An additional 170 interim cleanings (i.e., the cleaning of propellers and shafts only) are estimated to occur each year.[1]

Although flow rates from the SCAMP have not been measured, based on impeller characteristics, motor speed, and expected efficiency, the flow rate has been estimated to be 13,500 gallons per minute (gpm), or 51,100 liters per minute (L/min).[10]

3.2.2 Other Underwater Repair, Maintenance, and Inspection Processes

Table 1 lists the estimated releases from Navy underwater ship husbandry activities other than hull cleaning.[22] Coating shafts with fiberglass is performed on an infrequent basis. Sonar dome repairs are necessary only on submarines and surface combatants equipped with sonar equipment. The other listed activities apply to all vessels. Since the other services have fewer large ships than the Navy, these activities are expected to be less frequent among vessels of the other Armed Forces. For example, there have been three documented instances of underwater weld repairs conducted on MSC vessels in the past five years, and no rubber dome or fiberglass repairs.[23]

Fiberglass Repair. On Navy vessels, fiberglass shaft coatings are estimated to be applied

12 times per year. Based on operational experience, it is estimated that approximately one quart of resin could possibly be released per fiberglass wrapping event. Given this amount, it is estimated that 12 quarts (11.4 liters) of the resin system (i.e., resin mixed with hardener) could possibly be released per year.[22]

Welding. Small amounts of welding consumables can enter the marine environment through the dry habitat or directly when wet welding is performed.[11] Slag and spent welding rods may also be released. From operational experience, it is estimated that approximately five pounds of slag or spent welding rod are discharged during each underwater welding operation, and approximately 12 of these operations are performed fleet-wide each year on Navy ships.[22] Metals from the welding operation will not be readily dissolved in the surrounding waters and will fall to the harbor floor.

Sonar Dome Repair. A discharge of solid rubber waste and/or adhesive can result from this operation. This is a site-specific operation, and this discharge is dependent on the size of the patch being repaired. It is estimated that 19 Navy surface ships and submarines undergo sonar dome repairs yearly.[22] Rubber pieces from the sonar dome repair operations will not be dissolved in the surrounding water and will settle on the harbor floor.

Non-Destructive Test/Inspection. During magnetic particle inspection, a slurry of iron flakes is discharged directly through the water column. It is estimated that 20 Navy vessels undergo magnetic particle inspections yearly.[22]

Masker Belt Repairs. Waterborne repairs consist of cutting away damaged belt sections and installing replacement sections. Based on operational experience, it is estimated that six Navy vessels undergo masker belt repairs yearly.[22] Releases can occur from the removal of the damaged belt and the application of the epoxy sealer.[11] Similar to the epoxy resin used in propeller shaft repair, the epoxy sealant will quickly solidify into a hard, insoluble material.

Paint Operations. While a diver is performing in-water touchup painting with epoxy coatings, some paint can be incidentally released into the water in the vicinity of the painting operation. It is estimated that roughly 60 operations of this type are performed on Navy vessels annually.[24] The surface area involved may be as small as two square feet for a weld touchup, or as large as 1,500 square feet when several areas of the ship require touchup painting. The amount of paint released will vary with the size of the area painted and the skill of the operator.[1] The release of material during these operations is accidental and highly variable.

SEAWOLF Propulsor Layup. Current operational procedures require the PPCS to be installed with 12 hours after entering port when the in port time is expected to be greater than 72 hours.[2] Exceptions to this requirement exist for maintenance and engine testing, during which the PPCS will be removed, or perhaps not installed at all. This is similar to the requirement for putting the main condensers of earlier submarine classes on a fresh water layup for which an estimate of 6 times per year was developed.[3]

3.3 Constituents

Materials associated with underwater ship husbandry activities and which may be constituents of the various discharges are discussed in this section.

3.3.1 Underwater Hull Cleaning

The primary constituents found in the hull cleaning discharge are copper and zinc from the antifouling paint. These constituents are priority pollutants; neither are bioaccumulators. TBT is not a constituent of concern since small craft with aluminum hulls are not typically cleaned waterborne.[1]

3.3.2 Other Underwater Repair, Maintenance, And Inspection Processes

The primary constituents which may be found in the discharge from underwater repair, maintenance, and inspection processes other than hull cleaning are listed in the following paragraphs. Constituents which are classified as bioaccumulators or priority pollutants are identified.

Fiberglass Repair. The primary constituents found in the discharge from fiberglass repair activities are proprietary resins and fiberglass. The resin material is fluid for only a short period of time; will not be dissolved in the surrounding water; and will fall to the harbor floor, where it will complete its curing. The hardener can contain triethylenetetramine; tetraethylenepentamine; 2,4,6-tris(dimethylaminomethyl)phenol; and amidoamine.[25]

Welding. The primary constituents found in the discharge from underwater welding are metals in the slag associated with welding rods. These may contain chromium, iron, nickel, beryllium, manganese, and trace quantities of other metals.[11] Chromium, nickel, and beryllium are priority pollutants.

Sonar Dome Repair. The primary constituents found in the sonar dome repair discharge are rubber from the patches and the sealant. The sealant adhesive contains epoxy resin, amine polymer, iron oxide, and silica.[11]

Non-Destructive Test/Inspection. The primary constituents found in the discharge from crack or weld inspection are fluorescent iron powder or flakes, water conditioner, and a surfactant mixture suspended in water.[26] The particles used are required by specification to be non-toxic, finely divided ferromagnetic material free from rust, grease, oil, paint, or other materials which can interfere with their proper functioning.[14]

Masker Belt Repairs. The primary constituents found in the discharge from masker belt repairs are portions of the damaged belt and adhesive. Sealant adhesive contains amine polymer, iron oxide, and silica.[11]

Paint Operations. The primary constituents found in the discharge from touchup paint operations are epoxy paint which contains 4,4’-methylene dianiline, benzyl alcohol, and traces of epichlorohydrin.[11]

SEAWOLF Propulsor Layup. Constituents from the layup of the SEAWOLF propulsor will include decaying organic matter, and CPO that may build-up in the enclosed volume of the propulsor. CPO is the primary constituent.

3.4 Concentrations

3.4.1 Underwater Hull Cleaning

The Navy studied the environmental effects of in-water hull cleaning on six ships during the period from 1991-1993. Measurements of total copper were taken directly within the SCAMP discharge plume for three of these ships.[10] This data serves as the basis for the analysis of copper concentrations in and loading from the SCAMP effluent.

Table 2 summarizes both dissolved (0.45 micron filtered) and total (unfiltered) copper concentrations from the effluent of the SCAMP for the three ships.[10] Samples were collected in the plume created by the cleaning operation near the point of discharge, and thus are representative of the highest anticipated levels in the marine environment attributable to underwater hull cleaning. The mean for total copper in the samples ranged from 1,565 micrograms per liter (µg/L) to 2,619 µg/L. The dissolved fraction was 4 to 9 percent of the total copper (66 µg/L to 146 µg/L). Zinc levels were not measured in this study, but can be roughly estimated from the original ratio of constituents in the paint. Assuming a ratio of 2.5 parts copper to 1 part zinc, it can be estimated that the total zinc concentration is 626 to 1,048 µg/L.[27]

3.4.2 SEAWOLF Propulsor Layup

The concentration of organic matter in the released volume of water will be related to the amount of biological matter in the harbor water when the PPCS is installed. The concentration of CPO will be proportional to the current output of the ICCP system and the length of time the PPCS is installed, and inversely proportional to the oxidizable component of the harbor water at the time of PPCS installation.

Typical in port ICCP system output for the SEAWOLF Propulsor is less than 1 ampere. An equation based on Faraday’s Law is used to determine the maximum CPO generation rate of 1.3 g Cl/hr.

Generation Rate of Chlorine Produced Oxidants (CPO)

$$= (1\text{ amp})\,(1\text{ coulomb/amp-sec})\,(3{,}600\text{ sec/hr})\,(35.45\text{ g chlorine/mole})\,(\text{mole}/96{,}484\text{ coulomb})$$
$$= 1.323\text{ g chlorine/hr} \approx 1.3\text{ g/hr}$$

Since ICCP systems (i.e., anode materials and system operating voltage) are designed to maximize cathodic protection provided to the hull, and generation of chlorine or CPO is a secondary reaction, actual CPO generation rates are expected to be significantly lower.

This generation rate of CPO will be further offset by the consumption of CPO in the harbor water. In the first stage of CPO decay, a portion of the CPO disappears within one minute, consumed by the instantaneous oxidant demand. This first decay is assumed to be a 25% reduction, based upon a range of values reported for studies performed in waters between $0^{o}C$ and $33^{o}C$.[28, 29] Following this, decay is assumed to occur at a rate of 50% concentration reduction per hour. While actual decay rates for CPO will vary significantly due to temperature, flow, and amount of biological matter, these average decay rates can be used to determine an estimate of the resultant CPO concentration and mass loading as shown in Calculation Sheet 1.[30] The resultant concentration and mass loading converge to steady-state values of 18 µg/L CPO and 1.4 g CPO per event, respectively, in the enclosed volume of water after ten hours of system operation.

One set of field was data obtained for this application, and in this, a CPO concentration of less than 40 µg/L was measured in the enclosed water of the propulsor over a 52 day period.[31,32] This testing was accomplished in the context of local environmental limits for CPO of 0.2 ppm (200 µg/L), and test results only confirmed CPO concentrations within the lowest range of the test apparatus (0.0 ppm to 0.04 ppm) rather than precise values.[32] This is in agreement with the 18 µg/L estimated from the previous CPO decay calculation. The larger of the two estimates (40 µg/L) will be assumed for subsequent calculations.

3.4.3 Other Underwater Repair, Maintenance, and Inspection Processes

In accordance with the specifications, the concentration of magnetic particles in the slurry used for underwater weld inspection is between 0.1% and 0.7% by volume.[14] The remainder of the suspension is water. The estimated release amounts from other underwater ship husbandry activities are infrequent and in small quantities. In addition, these discharges are mostly insoluble and are unlikely to remain suspended in the water column or be dissolved. Pollutant concentrations resulting from fiberglass repair, welding, sonar dome repair, masker belt repair, and painting were not estimated.

4.0 NATURE OF DISCHARGE ANALYSIS

Based on the discharge characteristics presented in Section 3.0, the nature of the discharge and its potential impact on the environment can be evaluated. The estimated mass loadings are presented in Section 4.1. In Section 4.2, the concentrations of discharge constituents are compared with water quality criteria. In Section 4.3, the potential for the transfer of non-indigenous species is discussed.

4.1 Mass Loadings

4.1.1 Underwater Hull Cleaning

Differences in ship assignments and deployments create different rates of hull fouling on individual vessels. However, the decision to initiate hull cleaning operations is based on visual inspection and by ship performance indicators as outlined in NSTM, Chapter 081.[4] Based upon this standard approach to assessing the need for cleaning, it is reasonable to assume that cleaning operations are initiated under similar fouling conditions. Therefore, the SCAMP discharges sampled are assumed to provide a reasonable basis for the approximation of SCAMP discharges fleet-wide. The total volume of a release from an underwater hull cleaning operation is proportional to the area of the hull cleaned. Therefore, the total volume of the discharge is related to the class of ship, with larger releases generated from the cleaning of larger hull areas.

For the purposes of calculating mass loading from ships and the fleet, the mean concentration of the copper in the SCAMP discharge from the three vessels studied was used. The total copper was measured to be 1,950 μg/L and the dissolved copper fraction averaged approximately 107 μg/L, or approximately 5.5%.[10]

In order to calculate the mass loading, data are needed on the flow rate (F) from the SCAMP impellers, and the rate (R), or area cleaned per unit time. The mass of copper released (Cu) per unit area cleaned (A) can be calculated by the following formula:[10]

Cu/A = (Cu concentration) (F/R)
where Cu is in grams (g)
A is in square meters (m^2)
Cu concentration is in grams per liter (g/L)
F is in liters per minute (L/min)
R is in square meters per minute (m^2/min)

Using the following assumptions, a sample calculation of the mass of copper released per unit area cleaned is provided below:

SCAMP flow rate is 51,100 L/min (equivalent to 13,500 gpm), (Section 3.2)
Cu concentration = 0.00195 g/L (mean concentration)
Flow rate (F) = 51,100 L/min
Cleaning rate (R) = 20.8 m^2/min (225 ft^2 /min)
(based on 45 ft/min travel speed, and a 5 ft wide cleaned path)
Cu/Area = (0.00195 g/L) (51,100 L/min) / (20.8 m^2/min)
Copper release= 4.8 g Cu per m^2 of surface cleaned

Assuming the entire hull area exposed to the water is cleaned, the wetted surface area of the ships can be used for the area cleaned. The wetted surface area of the ships was taken directly from tables in NSTM Chapter 633, "Cathodic Protection," or estimated by the following formula presented in the same source:[33]

$$S = 1.7(L)(d) + (V/d)$$

where: S = wetted surface area (ft^2)
L = length between perpendiculars (ft)
d = molded mean draft at full displacement (ft)
V = molded volume of displacement ft^3
(for seawater, 35 ft^3 of water per ton displacement)

As an example for an individual ship, from the NSTM the Spruance Class destroyer has a wetted hull area of 35,745 ft^2 (3,321 m^2).[33] Therefore, the mass loading is estimated to be 15.9 kilograms (kg), or 35 pounds (lbs) total copper released during a full hull cleaning.

Fleetwide Hull Cleanings. A list of Navy vessels which received full hull cleanings during the period from 1993-1996 was used to determine a weighted average mean hull surface area cleaned annually.[21] This weighted average was estimated to be 2,973 m^2. The estimated copper release rate and the mean hull wetted surface area can be applied to all Navy ships to derive a total mass release fleet-wide. Dissolved copper releases are based on the average ratio (5.5%) of dissolved to total copper measured.[10]

Mean wetted hull area (all vessels) = 2,973 m^2
Approximate number of Navy vessels cleaned annually = 136
Total area cleaned annually = 404,328 m^2 (assuming full hull cleanings)
Total copper release = (4.8 g/m^2) (404,328 m^2) = 1,941 kg/yr; or 4,279 lbs/yr
Dissolved copper release = (1,941 kg/yr) (5.5%) = 108 kg/yr; or 238 lbs/yr

Since zinc was not measured in the Navy studies, it was assumed that releases from hull cleaning contain the same copper to zinc ratio (2.5:1) as is found in AF paint prior to its application.[27] The annual mass loading for zinc was estimated.

Total zinc release = (1,941 kg Cu/yr) / (2.5 (Cu/Zn ratio)) = 776 kg/yr; or 1,712 lbs/yr

4.1.2 SEAWOLF Propulsor Layup

Based on information previously provided, the annual mass loading of CPO due to the layup of the SEAWOLF propulsor is estimated to be a maximum of 19 g of chlorine.

> Annual mass loading = (concentration)(volume per discharge)(number of discharges)
>
> Maximum concentration = 40 μg/L (see Section 3.4.2)
> Volume per discharge = 21,000 gal (3.785 L/gal) = 79,500 L
> Number of discharges per year = 6
>
> Mass loading per event = 3.2 g CPO
> Maximum annual mass loading = 1.9×10^7 μg, or 19 g CPO

4.1.3 Other Underwater Repair, Maintenance, And Inspection Processes

Based on the information presented in Section 3.2 and Table 1, the total discharges associated with underwater ship husbandry operations outside of underwater hull cleaning are as follows:

- 12 quarts of fiberglass resin released annually from shaft coatings over the course of 12 events
- Approximately 60 pounds of welding consumables released annually, including spent welding rods and slag over 12 events

The estimated release amounts from other underwater ship husbandry activities are infrequent and in small quantities. In addition, these discharges are mostly insoluble and are unlikely to remain suspended in the water column or be dissolved.

4.2 Environmental Concentrations

Total copper has been measured in the effluent stream near hull cleaning operations at levels of approximately 1,600 to 2,600 μg/L.[10] These measured copper concentrations exceed water quality criteria (WQC) by three orders of magnitude. Dissolved copper in those same tests ranged from 66 to 146 μg/L, which is 28 to 61 times the Federal criterion for copper.

Using the compositional ratio of copper to zinc in antifouling paint, zinc concentrations in the release from underwater hull cleaning are estimated to be approximately 780 μg/L. This value exceeds WQC by one order of magnitude.

Table 3 shows Federal and most stringent state WQC relevant to the underwater ship husbandry discharge in comparison with the measured copper concentrations and estimated zinc concentrations from the SCAMP discharge.

For the SEAWOLF propulsor lay-up, most states have ambient WQC for CPO of 7.5 - 13 μg/L. The sole measured concentration available reported the concentration as being between 0 and 40 μg/L.

4.3 Potential for Introducing Non-Indigenous Species

Transport of non-indigenous species on the hulls of commercial vessels has been documented.[34] Although the cleaning practices, frequency of transits, and operating locations differ for the Armed Forces, there is the potential for non-indigenous species to be transferred. Fouling and the presence of marine organisms is most serious around intakes, grates, and sea chests.

5.0 CONCLUSIONS

Underwater ship husbandry has the potential to cause an adverse environmental effect because measured concentrations of copper and estimated concentrations of zinc from underwater hull scrubbing exceed ambient water quality criteria and these constituents are discharged in significant amounts. The potential also exists for introducing non-indigenous species during hull cleaning.

Discharges from the other ship husbandry operations are infrequent, and are small in terms of volume or mass loading. Therefore, these discharges have a low potential for environmental effect.

6.0 REFERENCES

To characterize this discharge, information from various sources was obtained, reviewed, and analyzed. Process information, engineering studies, and engineering analyses were used to estimate the rates of discharge and the concentrations of copper and zinc released to the environment. Table 4 shows the sources of data used to develop this NOD report.

Specific References

1. UNDS Equipment Expert Meeting Minutes - Underwater Hull Husbandry, 22 October 1996.

2. Wendel, A., Naval Sea Systems Command (SEA 03Z52), UNDS Equipment Expert Meeting Structured Questions, "Chlorine Produced from SEAWOLF Propulsor," 8 December 1997.

3. McFarland, L., SUBLANT. Freshwater Layup, Submarine Main Steam Condensers. Personal Communication. Miller, R.B., M. Rosenblatt & Son, Inc., 7 January 1997.

4. Naval Ships' Technical Manual (NSTM) Chapter 081, Waterborne Underwater Hull Cleaning of Navy Ships. 4 August, 1997.

5. NAVSEA Standard Work Item (SWI 009-32) FY-98, Cleaning and Painting Requirements.

6. Qualified Products List of Qualified Products Under Military Specification MIL-PRF-24647 Paint System, Anticorrosive and Antifouling, Ships Hull. QPL-24647-3, 2 April 1996.

7. Military Specification, MIL-PRF-24647B, "Paint System, Anticorrosive and Antifouling, Ship Hull," August 1994.

8. UNDS Equipment Expert Meeting Minutes - Hull Coating Leachate Discharge, M. Rosenblatt & Son, Inc., 20 August 1996,

9. Naval Ships' Technical Manual (NSTM) Chapter 631, Preservation of Ships in Service, Volume 3, Section 8. 1 November 1992.

10. The Naval Command, Control, and Ocean Surveillance Center, RDT&E Division, Marine Environmental Support Office, San Diego, California. "UNDS Underwater Hull Husbandry Evaluation: In-Water Hull Cleaning." 13 February 1997.

11. Naval Sea Systems Command Code 00C, Underwater Ship Husbandry: Compilation of Summary Sheets and Material Safety Data Sheets for the UNDS Program, 1997.

12. Military Standard for "Glass Reinforced Plastic Coverings for Propeller Shafting," MIL-STD-2199, 11 May 1990.

13. Naval Ships' Technical Manual (NSTM) Chapter 074, Volume 1, Section 6.1-6.9.4.3, Welding and Allied Processes, 15 June 1995.

14. Military Standard for "Requirements for Non-Destructive Testing Methods", MIL-STD-271F(SH), 27 June 1986.

15. Rosner, LCDR J., Naval Sea Systems Command, Code SEA 00C. Information on Fiberglass Repair Processes, Personal communication, K. Thomas, M. Rosenblatt and Son, Inc., 19 February 1998.

16. Material Safety Data Sheets for U.S. Technologies Limited Hycote 461 Epoxy Resin Fairing Compound, Hycote 461 Curing Agent, Hycote 151 Epoxy Resin (November 1990), and Hycote 151 Curing Agent (December 1991).

17. White, G.C. The Handbook of Chlorination and Alternative Disinfectants. New York, Van Nostrand Reinhold, 1992, p.1308.

18. Aivalotis, J., USCG, Use of TBT on USCG Ships, L. Panek, Versar, Inc., 28 May 1997.

19. Welling, J., Army. “Hull Cleaning Practices of the Army,” Personal communication, M. DiValentin, Naval Sea Systems Command, SEA 03L, 2 June 1997.

20. UNDS Ship Database, August 1, 1997.

21. Naval Sea Systems Command, SEA 00C. Computer Assisted Information Retrieval System (CAIRS) Underwater Ship Husbandry Database Retrieval, September 1997.

22. Dean, M., Naval Sea Systems Command, SEA 00C. Memorandum to M. Wenzel, NSWCCD Code 632, 10 April 1996.

23. Weersing, P., Military Sealift Command. Underwater Ship Husbandry Activities of the MSC, Personal communication to UNDS file. 16 April 1997.

24. Naval Sea Systems Command, SEA 00C. Underwater Ship Husbandry Paint Operations Data from May 1996 through August 1997.

25. Material Safety Data Sheet for ITW Philadelphia Resins, PHILLYCLAD 1775/620TS Resin, 7 October 1996.

26. Material Safety Data Sheet for Circle Systems, Inc. Mi-Glow Underwater 1, May 1995.

27. Material Safety Data Sheet for Courtaulds BRA 640 Interviron Red Antifouling Paint, March 1996.

28. Davis, M.H. and J. Coughlan. “A Model for Predicting Chlorine Concentrations within Marine Cooling Circuits and its Dissipation at Outfalls,” in Water Chlorination: Environmental Impact and Health Effects, Vol. 4, Book 1, Eds. Jolley, R.L. et al., Ann Arbor Science, 1983.

29. Naval Sea Systems Command, SEA 03L. Chlorination Report, Malcolm Pirnie, Inc., 14 July 1997.

30. Thomann, R. V. and J. A. Mueller. Principles of Surface Water Quality Modeling and Control. Harper Collins Publishers, New York, NY. 1987. pp. 180-185.

31. Electric Boat Corporation, Supplemental Information Relative to SEAWOLF Propulsor NOD, Alan Wendel, Naval Sea Systems Command, 16 December 1997.

32. Electric Boat Corporation, "SEAWOLF PPCS/ICCP System Compatibility" Draft Engineering Report, 10 June 1998.

33. Naval Ships' Technical Manual (NSTM) Chapter 633, Section 4.3.1 and Table 633-5. Cathodic Protection. 1 August 1992.

34. Ruiz, Greg. Non-Indigenous Species Presentation - Notes by Dan G. Mosher, Malcolm Pirnie, Inc. 18 September 1996.

General References

USEPA. Toxics Criteria for Those States Not Complying with Clean Water Act Section 303(c)(2)(B). 40 CFR Part 131.36.

USEPA. Interim Final Rule. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance – Revision of Metals Criteria. 60 FR 22230. May 4, 1995.

USEPA. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants. 57 FR 60848. December 22, 1992.

USEPA. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California, Proposed Rule under 40 CFR Part 131, Federal Register, Vol. 62, Number 150. August 5, 1997.

Connecticut. Department of Environmental Protection. Water Quality Standards. Surface Water Quality Standards Effective April 8, 1997.

Florida. Department of Environmental Protection. Surface Water Quality Standards, Chapter 62-302. Effective December 26, 1996.

Georgia Final Regulations. Chapter 391-3-6, Water Quality Control, as provided by The Bureau of National Affairs, Inc., 1996.

Hawaii. Hawaiian Water Quality Standards. Section 11, Chapter 54 of the State Code.

Mississippi. Water Quality Criteria for Intrastate, Interstate and Coastal Waters. Mississippi Department of Environmental Quality, Office of Pollution Control. Adopted November 16, 1995.

New Jersey Final Regulations. Surface Water Quality Standards, Section 7:9B-1, as provided by The Bureau of National Affairs, Inc., 1996.

Texas. Texas Surface Water Quality Standards, Sections 307.2 - 307.10. Texas Natural Resource Conservation Commission. Effective July 13, 1995.

Virginia. Water Quality Standards. Chapter 260, Virginia Administrative Code (VAC) , 9 VAC 25-260.

Washington. Water Quality Standards for Surface Waters of the State of Washington. Chapter 173-201A, Washington Administrative Code (WAC).

Committee Print Number 95-30 of the Committee on Public Works and Transportation of the House of Representatives, Table 1.

The Water Quality Guidance for the Great Lakes System, Table 6A. Volume 60 Federal Register, pg. 15366. March 23, 1995.

Table 1 - Releases Associated with Underwater Ship Husbandry on Navy Vessels (Exclusive of Hull Cleaning)[22]

Operation	Material Released	Quantity Released per Event	Events per Year
Underwater Fiberglass Repair	fiberglass resin	1 quart	12
Underwater Welding	epoxy paint, welding consumable, slag	5 lbs. (welding consumables)	12
Rubber Sonar Dome or Sub Tile Repair	rubber sealant, epoxy	minimal	16 (surface ships) 3 (submarines)
Non-Destructive Testing	iron flakes, dye, surfactant	minimal	20
Masker Belt Repairs	epoxy paint and filler; rubber sealant	minimal	6
Paint Operations Underwater/Waterline	epoxy paint	minimal	60
Propulsor Protective Covering System (PPCS)	chlorine produced oxidants (CPO)	3.2 g	6

Table 2 - Total And Dissolved Copper Concentrations From In-Water Hull Cleaning Effluent Generated By SCAMP[10]

Vessel Name	Cu, µg/L (Filtered)	% Dissolved	Cu, µg/L (Unfiltered)
USS Fort Fisher (LSD 40)	66	4	1,668
USS Tuscaloosa (LST 1187)	141		1,475
	146		1,520
	137		1,600
	125		1,597
	135		1,633
mean:	136.8	8.7	1,565
standard deviation:	+/- 7.0		+/- 58.3
USS Ranger (CV 61)	106		2,499
	116		2,503
	118		3,287
	120		2,441
	124		2,362
mean:	116.8	4.5	2,619
standard deviation:	+/- 6.0		+/- 338
Grand Mean:	106.5	5.5	1950
standard deviation:	29.8		474

Table 3. Comparison of Constituent Concentrations with Water Quality Criteria (μg/L)

Constituent	Concentration	Federal Acute WQC	Most Stringent State Acute WQC
Copper (total)	1950	2.9	2.5 (WA)
Copper (dissolved)	107	2.4	2.4 (CT, MS)
Zinc (total)	780	95.1	84.6 (WA)
CPO	0 - 40	-	10 (FL)

Notes:
Refer to federal criteria promulgated by EPA in its National Toxics Rule, 40 CFR 131.36 (57 FR 60848; Dec. 22, 1992 and 60 FR 22230; May 4, 1995)

CT = Connecticut
FL = Florida
MS = Mississippi
WA = Washington

Table 4. Data Sources

	Data Source			
NOD Section	**Reported**	**Sampling**	**Estimated**	**Equipment Expert**
2.1 Equipment Description and Operation				X
2.2 Releases to the Environment	X			X
2.3 Vessels Producing the Discharge	UNDS Database			X
3.1 Locality				X
3.2 Rate	X			
3.3 Constituents	MSDS			X
3.4 Concentrations	X			
4.1 Mass Loadings			X	
4.2 Environmental Concentrations			X	
4.3 Potential for Introducing Non-Indigenous Species				X

Chlorine Produced Oxidants (CPO) generation rate (R) = 1.3 g/hr
PPCS volume (V) = 21,000 gal (3.785 L/gal) = 79,485 L

C_0 = concentration after first minute (considered "time zero" due to first stage decay)
= [(1.3 g/hr) (0.75) (10^6 μg/g)] / (79,485 L) = 12.3 μg/L
C_t = concentration at a given time (t)
$C_t = C_0 e^{(-kt)}$, where k = decay constant
$\ln (C_t/C_0) = \ln (e^{(-kt)}) = -kt$
For t = 1 hr and C_0 = 12.3 μg/L, Ct = (12.3μg/L) (50%) = 6.15 μg/L
$\ln (C_t/C_0)$ = ln (12.3/6.15) = ln (0.5) = -0.693 = -kt
k = - (-0.693) / (1 hr) = 0.693 / hr
$C_t = C_0 e^{(-kt)}$ = (12.3 μg/L) $e^{(0.693t)}$

However, since CPO is generated simultaneously with the decay of previously introduced CPO, a steady state concentration will be reached when the decay rate equals the generation rate, which can be expressed as:[30]

$k(C_{ss}V) = 0.75R$
k = decay constant (hr^{-1})
$C_{ss}V$ = (steady state CPO concentration) (volume) = mass (g)
R = generation rate (g/hr)

$C_{ss} = 0.75R / (kV)$
C_{ss} = 17.7 μg/L

Mass = 1.4 g CPO/event or 8.4 g CPO/yr

Calculation Sheet 1. CPO Concentration and Mass from SEAWOLF Propulsor Layup