ESTCP
Cost and Performance Report

(WP-200528)

Zero VOC, Coal Tar Free Splash Zone Coating (SZC)

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AIM	architectural and industrial maintenance coating
AQMD	Air Quality Management District
AST	aboveground storage tank
ASTM	American Society for Testing and Materials
CCB	construction criteria base
CCS	coating condition survey
CNO	Chief of Naval Operations
COTS	commercial off-the-shelf
CPUA	cost per unit area
DFT	dry film thickness
DoD	U.S. Department of Defense
DOT	Department of Transportation
DPS	Detailed Performance Standard
ECAM	Environmental Cost Analysis Methodology
EICO	Engineering Innovation and Criteria Office
ESTCP	Environmental Security Technology Certification Program
HAP	hazardous air pollutant
IMC	industrial maintenance coating
LF	linear feet
LP	liquid polysulfide
MIBK	methyl isobutyl ketone
MPI	Master Painters Institute
NAS	Naval Air Station
NAVSTA	Naval Station
NAVFAC	Naval Facilities Engineering Command
NFESC	Naval Facilities Engineering Service Center
NTPEP	National Transportation Product Evaluation Program
OEM	original equipment manufacturer
OSD CPC	Office of the Secretary of Defense Corrosion Prevention and Control
OSHA	Occupational Safety and Health Administration
P2	pollution prevention
PCS	Premier Coating System
POC	point of contact

PRV	plant replacement value
PS	paint system
QA	quality assurance
QC	quality control
SBIR	Small Business Innovative Research
SCAQMD	South Coast Air Quality Management District
SF	square foot
SSP	steel sheet piling
SSPC	Society for Protective Coatings
SZC	splash zone coating
TCLP	toxic characteristic leaching procedure
TOC	total ownership cost
UFGS	Unified Facilities Guide Specification
UHPWJS	ultra-high pressure water jetting system
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet
VOC	volatile organic compounds

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1.0 EXECUTIVE SUMMARY

1.1 OBJECTIVES OF THE DEMONSTRATION

The "splash zone" is defined as the area between the year's lowest tidal mark and up to 10 feet above the year's highest tidal mark. It is extremely difficult to protect steel structures against corrosion in this zone where corrosion rates have been documented to exceed 30 mm per year on unprotected steel. This is more than six times the corrosion rate typically found on steel under constant water immersion.

Specific guidance for coating the Navy's steel sheet piling employs two coating system options for the initial painting of steel placed in seawater immersion/splash zones: 1) three coats of epoxy-polyamide or 2) two coats of coal tar pitch epoxy-polyamide. In theory, the three-coat epoxy system should provide better in-place service than the two-coat coal tar epoxy system. In practice, the coal tar system is used almost exclusively due to the lower material cost. The coal tar system provides approximately five years of splash zone service before maintenance is required which can include complete removal and reapplication. However, maintenance is rarely done due to the high cost and environmental issues that need to be addressed.

The environmental issues associated with the two coating system options include high volatile organic compounds (VOC) content, hazardous air pollutants (HAP), and may also include hazardous pigment content. The coal tar epoxy also contains coal tar pitch which is regulated by the Occupational Safety and Health Administration (OSHA) due to known human carcinogen content. The product developed under this effort is 100% solids and therefore has no VOC content, has no coal tar pitch, and exceeds the field performance of the two current coating system options.

1.2 TECHNOLOGY DESCRIPTION

The first liquid polysulfide polymer became commercially available in 1943. Today, there are several liquid polysulfide polymers, each with distinctly different properties but similar in chemical structure. The liquid polysulfides have the advantage of being room-temperature vulcanized, meaning they can be cured at ambient temperatures after the addition of an oxygen-donating curing agent.

Epoxy resins date back to about 1949. Their many excellent properties include rapid curing at normal temperatures, good adhesion to most surfaces, toughness, and chemical resistance. Today, versatile epoxy resin compounds and systems are customized to meet the different physical properties required by various markets. None of the commercially tested coatings met the desired Navy performance requirements. The two most significant limitations were the inability of the commercial coatings to adequately bond to clean, semi-damp steel and insufficient curing under immersion. To make a flexible epoxy that could potentially meet the requirements of the splash zone coatings (SZC), a liquid polysulfide polymer was used. The polysulfide addition improves certain physical properties without adversely affecting the existing performance capabilities of the epoxy resin.

1.3 DEMONSTRATION RESULTS

Naval Facilities Engineering Command's (NAVFAC) Small Business Innovative Research (SBIR) program solicited the topic entitled "Polysulfide Modified Epoxy Novolac Cladding for Steel Immersion/Splash Zone Service." Naval Facilities Engineering Service Center (NFESC) subsequently awarded Phase I and Phase II work to PolySpec Corporation and Polymeright, Incorporated. Phase I results were promising whereas preliminary Phase II results were exceptional. The tests included small-scale application trials under actual field conditions.

Early SBIR-funded studies of the SBIR-developed polysulfide modified novolac epoxy formulation (renamed Zero VOC, Coal Tar Free Splash Zone Coating) indicated that the SZC will provide at least twice the performance compared to the currently specified coating systems. This demonstration provides a full-scale validation of the SZC for use as an in-service waterfront maintenance system and enables the transition of this coal tar free coating directly into the hands of Department of Defense (DoD) end-users who require waterfront metal (e.g., sea walls, sheet pile) maintenance painting.

1.4 IMPLEMENTATION ISSUES

This project addresses Air Force, Army, and Navy performance and environmental requirements for sustainability and reduction of VOC and HAP emissions in the use of such SZCs. Federal, state, and local environmental agencies such as the Environmental Protection Agency (EPA) and Air Quality Management Districts (AQMD) across the country classify many VOCs as hazardous and restrict their emissions through regulations such as the Clean Air Act and local EPA and AQMD rules. Chief of Naval Operations (CNO) directives require significant reductions in the amount of hazardous waste generated by the Navy. This technology will satisfy all of these requirements due to the SZC being free of toxic metals, hazardous air pollutants, coal tar pitch, and VOCs.

2.0 INTRODUCTION

2.1 BACKGROUND

The "splash zone" is defined as the area between the year's lowest tidal mark and up to 10 feet above the year's highest tidal mark. It is extremely difficult to protect steel structures against corrosion in this zone where corrosion rates have been documented to exceed 30 mm per year on unprotected steel. This is more than six times the corrosion rate typically found for steel placed in water below the intertidal zone. The Navy owns about 650,000 linear feet (LF) of waterfront bulkheads, quay walls, and seawalls with a plant replacement value (PRV) of about $1.24 billion. About 30% of these waterfront structures are composed of steel sheet piling (SSP). The annual cost for maintaining these SSP structures is approximately $20 million.

Unified Facilities Guide Specification (UFGS) – 09967 "Coating of Steel Waterfront Structures" is used to specify coating of the Navy's steel sheet piling. It employs two coating system options for use in the initial painting of steel placed in sea water immersion/splash zones:

- Three coats epoxy-polyamide (Society for Protective Coatings [SSPC] Paint System [PS] 13.01), or
- Two coats coal tar pitch epoxy-polyamide (SSPC PS 11.01).

In theory, the three-coat epoxy system should provide better in place service than the two-coat coal tar epoxy system. Historically and in practice, the coal tar system is almost exclusively used due to the lower material cost. Nonetheless, the coal tar system provides approximately five years of splash zone service before complete removal and reapplication would be required to prevent the more aggressive corrosion of the exposed substrate. Despite the need for recoating or planned maintenance, it is rarely done due to the high cost and environmental issues that need to be addressed.

Each coat of coating system SSPC PS 13.01 contains 300 g/L of VOCs, HAPs of methyl isobutyl ketone (MIBK) and xylene, and the pigment chromium oxide. Each coat of SSPC PS 11.01 contains 30% by weight coal tar pitch (regulated by OSHA: known human carcinogen, National Toxicology Program), 192 g/L of VOCs, and xylene (HAP).

In effect since August 2002, California's South Coast Air Quality Management District (SCAQMD), Rule 1113 "Architectural Coatings," requires all industrial maintenance coatings (IMC), including SZCs, to contain no more than 100 g/L of VOCs effective August 2006.[1,2] The initial shop application of UFGS 09 97 13.26 to a typical 1000 ft long, 20 ft high (20,000 square foot [SF]) sheet pile bulkhead releases 597 lb of VOCs, contains 847 lb of coal tar pitch, and is not suitable for in-service maintenance painting.

In 2001, NFESC assessed commercially available coatings for use in splash zone maintenance, including shop application under simulated marine conditions. It was determined that the commercially available coatings did not perform any better than the SZCs being used. As a result, in FY 2002, the NAVFAC SBIR program solicited the topic entitled "Polysulfide Modified Epoxy Novolac Cladding for Steel Immersion/Splash Zone Service." NFESC

subsequently awarded Phase I and Phase II work to PolySpec Corp. and Polymeright, Inc.. Phase I results were promising whereas preliminary Phase II results were exceptional. The tests included small-scale application trials under actual field conditions. These studies indicated that the SBIR-developed formulation, renamed as the Zero VOC, Coal Tar Free Splash Zone Coating, will provide at least twice the performance compared to the currently specified coating systems. The estimated performance is based on comparative laboratory- and small-scale testing.

2.2 OBJECTIVES OF DEMONSTRATION

This demonstration provides a full-scale validation of the SZC for use as an in-service waterfront maintenance system and enables the transition of this coal tar free coating directly into the hands of DoD end-users who require waterfront metal (e.g., sea walls, sheet pile) maintenance painting.

Demonstration results are in the process of transitioning into commercial guidance such as a new Master Painters Institute (MPI) Detailed Performance Standard (DPS) for the SZC. Results will be amending the coating systems employed by UFGS-09967 "Coating of Steel Waterfront Structures." The DPS and the amended UFGS will be web-displayed at http://www.paintinfo.com and http://www.wbdg.org/ccb/browse_org.php?o=70 respectively, for direct use by Tri-service activities with splash zone steel in need of either new or maintenance painting. In addition, results will be posted at the Joint Service Pollution Prevention (P2) Library and presented at the Tri-service Environmental Centers' Coordinating Committee meeting, if applicable. Intended technology users are the Navy, Army, Air Force, Marines, Bureau of Reclamation, and private industry.

2.3 REGULATORY DRIVERS

The project addresses the following requirements:

- Army Task N.312/N.000-08: Sustainable Painting Operations for the Total Army
- Air Force Need 200-204: Reduce VOC Emissions from Paint Application Systems
- Air Force Need 200-240: Methods to Reduce VOC Emissions/Hazardous Waste from Paint
- Navy 2.1.01.g: Control/Reduce Emissions from Coating, Stripping and Cleaning Operations
- Navy 2.1.01.q: Control of VOC and HAP Emissions
- Navy 3.1.04.a: Shipboard Paint and Coating Systems
- Navy 3.1.04.e: Minimize Paint Application Wastes

Federal, state, and local environmental agencies such as the USEPA and California AQMD classify many VOCs as hazardous and restrict their emissions through regulations such as the Clean Air Act and local USEPA and AQMD rules. CNO directives require significant reductions in the amount of hazardous waste generated by the Navy. This technology will satisfy

all of these requirements because the SZC is toxic metal free, is hazardous air pollutant free, contains no coal tar pitch, and is formulated without VOC.

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3.0 DEMONSTRATION TECHNOLOGY

3.1 TECHNOLOGY DESCRIPTION

The first liquid polysulfide polymer became commercially available in 1943, 13 years after the Thiokol Corporation developed and marketed a millable gum polysulfide known as the first synthetic rubber commercially made in the United States. Today, there are several liquid polysulfide polymers, each with distinctly different properties, but similar in chemical structure. To a large extent, products made from liquid polysulfide polymers have the same excellent overall solvent resistance properties as the millable gum polysulfides. However, the liquid polysulfides have the advantage of being room-temperature vulcanized, meaning they can be cured at ambient temperatures after the addition of an oxygen-donating curing agent (Figure 1).

$$\mathbf{HS(C_2H_4OCH_2OC_2H_4SH)_6C_2\ H_4OCH_20C_2H_4SH}$$

Figure 1. Disulfide linkages. (Thiol Terminal Groups: -SH)

Liquid polysulfide polymers are classified as high-quality, application-proven products that can be compounded as sealants, adhesives, coatings, potting compounds, and flexible molding compositions. They are also used for impregnating leather and other porous materials. Compounds based on these polymers are used in industrial and building construction, insulation, glass, aerospace, electronics, aviation, marine, and many other industries.

The manufacturing process for liquid polysulfide polymers follows the general method of chemical preparation whereby an organic dihalide is reacted with sodium polysulfide at elevated temperatures. A controlled amount of a trifunctional organic halide, which serves to introduce cross-linking sites, is co-reacted in the process. These cross-linking sites permit a range of elongation and modulus properties of the cured polymer.

Epoxy resins date back to about 1949. Their many excellent properties include rapid curing at normal temperatures, good adhesion to most surfaces, toughness, and chemical resistance to almost all dilute acids, alkalis, and solvents. Early uses included heavy-duty industrial paints and structural adhesives in the aircraft industry.

Today, epoxy resin compounds are widely used in construction, marine, electrical, and industrial markets. However, in order to meet the different physical properties required for these various markets, certain characteristics of the early epoxy systems have been changed. To make an epoxy flexible, the addition of a liquid polysulfide polymer can be used. The polysulfide addition does improve certain physical properties without adversely affecting the existing performance capabilities of the epoxy resin.

Versatile systems are possible by co-reacting polysulfides with epoxy resins (Figure 2). Liquid polysulfides (LP) function well as epoxy curatives because of the extreme reactivity of the mercaptide ion created in the presence of an epoxy resin and tertiary amine. The mercaptide ion

is formed when the mercaptan donates its hydrogen. The mercaptan ion adds to the epoxide group and displaces the tertiary amine to form a covalent sulfur-carbon bond. The tertiary amine is regenerated and is then available to react with another oxirane group. These systems exhibit the toughness and adhesion of epoxy and show the improved impact and general chemical resistance of polysulfide.

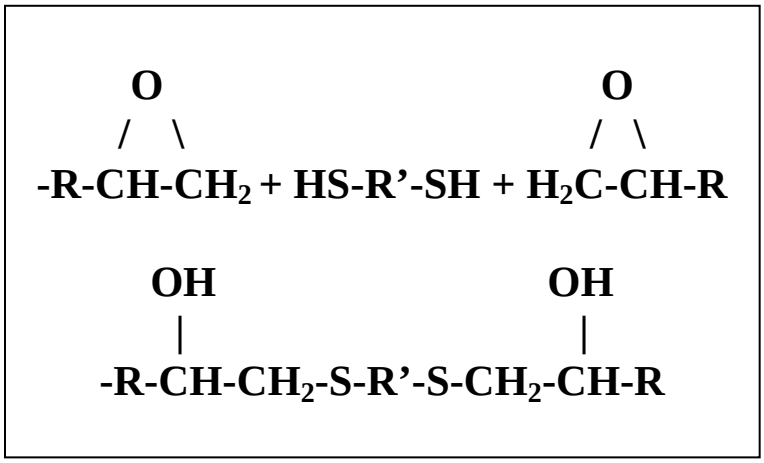

Figure 2. Co-reaction of polysulfides with epoxy resins.

Three different epoxy resins can be used with polysulfides: 1) bisphenol A, 2) bisphenol F, and 3) novolac. Each epoxy resin has its own special attributes as follows:

Bisphenol A – low cost, low viscosity, high epoxide content liquid resin ideal for coatings, adhesives, casting, potting, encapsulation, and wet lay-up applications.

Bisphenol F – more expensive, lower viscosity than A, and improved chemical resistance. It is more resistant to inorganic acids than bisphenol A.

Novolac – a high viscosity semisolid to solid resin with multiple functional groups, with increased cross-link density, better physical properties at elevated temperatures, and improved solvent and chemical resistance compared to bisphenol A and F.

Polysulfide polymers, with a glass transition temperature of about -65º F, remain flexible even at very low temperatures and when subjected to the stresses caused by thermal shock, including impact, will remain pliant rather than crack or disbond. Through the incorporation of epoxy into the polysulfide backbone, the glass transition temperature does rise but remains flexible even at temperatures below -20º F.

Application equipment has advanced significantly in recent years. Polysulfide materials can now be applied without any solvent dilution. Using heated lines, the material is uniformly atomized, giving a smooth coating with good aesthetics. The coating system can now be applied at up to 100 mm in a single pass. Furthermore, the formulated material allows the coating system to be edge retentive, thus overcoming a long-standing challenge for structural steel and other applications.

According to OSHA's Hazard Communication Standard, LP products are classified as non-hazardous. They are neither eye nor skin irritants, do not cause allergic skin reactions, and are not toxic when administered orally, making LP a safe alternative to amines in curing epoxy systems.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Compared to other commercially available SZCs, the main advantages of the SBIR-developed SZC are:

- Compliant with current/future VOC requirements for USEPA, state, district and regional counties.
- Elimination of environmental fines associated with VOC, HAP, and other regulations.
- Reduced coating removal collection/treatment/disposal costs.
- Reduced facility Total Ownership Cost (TOC).
- Rapid splash zone steel coating maintenance.
- Enhanced waterfront steel corrosion control.
- Flexible, corrosion resistant coating with ability to flex with sea wall movement.
- Maximum adhesion to water blasted steel.
- Impact and abrasion resistant.
- Resistant to cathodic disbondment.
- Ability to cure underwater.
- Edge retentive.
- Free of coal tar pitch.

The main limitations of the SBIR-developed SZC are:

- Requires semi-specialized but commercial off-the-shelf (COTS) surface preparation/application equipment.
- Requires semi-specialized contractor skill.

Table 1 provides a comparison of the commercially available SZCs previously tested to the SBIR-developed SZCs and to a recently developed commercial product, Premier Coating Systems (PCS) #1200TA, a 100% solids, glass flake filled epoxy.[3, 4, 5, 6, 7, 8] This PCS coating, selected as the commercial baseline control coating for this demonstration project, represents a second generation high performance marine coating that contains no HAPs, contains no other hazardous chemicals, develops very good adhesion to marginally prepared surfaces (surface tolerant), and complies with future SCAQMD VOC regulations. This new, glass flake filled

epoxy coating meets all of the objectives of the demonstration project and the coatings developed under this project. The new commercial coating together with the SZCs developed under this program will provide the baseline performance requirements for a non-government standard.

PCS #1200TA is typically used as a direct-to-metal, surface tolerant, high build, protective maintenance coating. It is used on bulkheads, miter gates, tainter gates, storage tanks and containment, piping, various structural steel and limited concrete surfaces, machinery, plant equipment, marine vessels and barges, offshore structures, and other surfaces exposed to humidity, fuel, chemicals and corrosive environments. It is applied using brush, roller, airless spray, or plural component spray. The cost per gallon is about $70.00 and is generally applied at approximately 25 mm dry film thickness (DFT) for a material cost of $1.09/SF at 25 mm. Surface preparation and coating application costs for in-service corroding SSP depend upon numerous factors and can start as low as $5.00/SF for ultra-high pressure water jetting system (UHPWJS) followed by $2.00/SF for airless spray application. According to these estimates, a conservatively low estimate to install PCS #1200TA to marginally prepared in-service SSP may start at approximately $8.00/SF.

Table 1. 2005 comparison of SZCs.

Coating	SZC	Surface Tolerant (adhesion)	Volume Solids	VOCs[a]	HAPs	Other Hazards
Kop-Coat A-788 Epoxy Putty	Yes	Poor-	100%	≈0 g/L	None	Silica, chrome green, carbon black
Interzone 954 High Build Epoxy	Yes	Good	85%	163 g/L (not met)	>5% xylenes, >0.05% MIBK	None
Interzone 1000 Glass Flake Epoxy	Yes	Poor-	92%	75 g/L	>1% xylenes	Silica, if aggregate used
Premier Coating Systems: PCS #1200TA Glass Flake Epoxy	Yes	Good+	100%	≈0 g/L	None	None
PolySpec: Thiokol LPE 5100 Splash Zone Coating	Yes	Excellent	100%	≈0 g/L	None	None
Polymeright: CP Chem TZ-R 904	Yes	Excellent-	100%	≈0 g/L	None	None

[a]SCAQMD Rule 1113 <100 g/L

4.0 PERFORMANCE OBJECTIVES

Table 2 summarizes performance objectives for the SZC in terms of primary performance criteria and expected performance metrics. Performance objectives are further defined in section 5, tTable 4 and include performance criteria, expected performance metric, and confirmation methods.

Table 2. Primary performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative	Pre-demonstration condition survey for substrate condition and SZC patch employing performance metrics for corrosion, peeling, blistering, tape adhesion, pull-off adhesion, film thickness, and SZC patch test adhesion.	Meet minimum pre-demonstration condition survey performance criteria as defined in table 4.	Met the requirements
Quantitative	Enhanced corrosion protection using performance metrics documenting one-year and four years field performance for corrosion, peeling, blistering, tape adhesion, pull-off adhesion, film thickness, cracking/checking, chalking, biological growth, and dirt pick-up.	Anticipated 50% increase in service life based upon meeting individual field performance criteria as defined in table 4.	Preliminary results support minimum 50% increase in service life to more than double

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5.0 SITE/PLATFORM DESCRIPTION

California's SCAQMD requires all architectural and industrial maintenance coatings (AIM), including SZCs, to contain no more than 100 g/L of VOCs. This is the most stringent standard for AIM VOCs. After initial screening of numerous potential sites, four DoD sites with SSP in need of maintenance painting were visually assessed for demonstration suitability; three in California and one in Florida. One of the two demonstration sites selected is located at the Naval Station (NAVSTA) San Diego, California, and the other is at the Naval Air Station (NAS) Pensacola, Florida. Each selected SSP structure was shop coated with two coats of coal tar epoxy and subsequently driven in front of in-place SSP structures. The NAS Pensacola SSP was put in place in 1980 (Figure 3). The installation date of the San Diego sheet piling (Figure 4) was not determined. After a successful Coating Condition Survey (CCS) as defined in Table 3 was completed, demonstrations were initiated on 14,700 SF of heavily corroded SSP at NAS Pensacola and approximately 10,400 SF of moderately corroded SSP at NAVSTA San Diego. NAVSTA and NAS personnel, PolySpec, Polymeright and the DoD technical points of contact (POC) were involved in initiating these demonstrations.

Figure 3. Demonstration site at NAS Pensacola before coating application.

Figure 4. Demonstration site at NAVSTA San Diego before coating application.

5.1 TEST PLATFORMS/FACILITIES

The demonstration sites are located at Bulkhead 303 Pensacola (see Figures 5 and 6) and the quay wall between Piers 1 and 2 San Diego (see Figures 7 and 8).[9] Each site is subjected to sea water immersion and splash, moderate to heavy industrial pollution (e.g., acidic fog and dew), biofouling (e.g., mussels, barnacles, algae), and ultraviolet (UV) exposure. These facilities are typical for Naval Facilities which owns about 816 million SF of seawalls/waterfront bulkheads. Bulkhead 303 Pensacola was reportedly installed in 1980.

The NAS Pensacola is located in Escambia County about 5 mi from downtown Pensacola in the westernmost part of the Florida Panhandle. It is situated on a peninsula bounded on the south and east by Pensacola Bay, and on the north by Bayou Grande. According to the "Naval Air

Station Master Plan, Naval Complex Pensacola," the mission of the activity is to support units of the Naval Air Training Command and other tenant activities.[10]

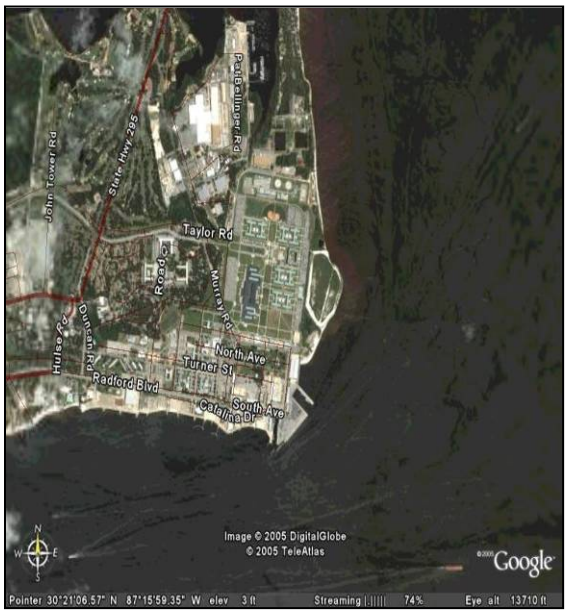

Figure 5. Pensacola, FL site.

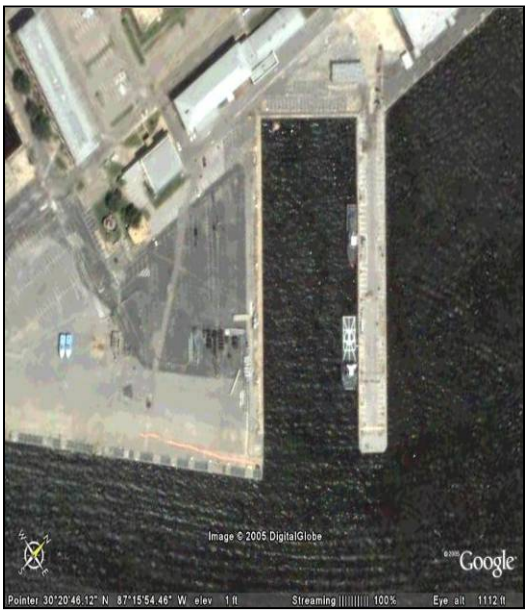

Figure 6. Bulkhead 303 Pensacola.

NAVSTA San Diego is located on the Eastern Shore of San Diego Bay about 16.5 mi from the entrance to the Bay[11]. The NAVSTA is homeport to approximately 60 Navy ships and to 50 separate commands, each having specific specialized fleet support purposes. The mission of the NAVSTA includes ship support and pier berthing space for more than 3500 ship movements performed annually[12]. Several facility inspections have been performed for use in assessing the condition NAVSTA San Diego waterfront structures.[13, 14]

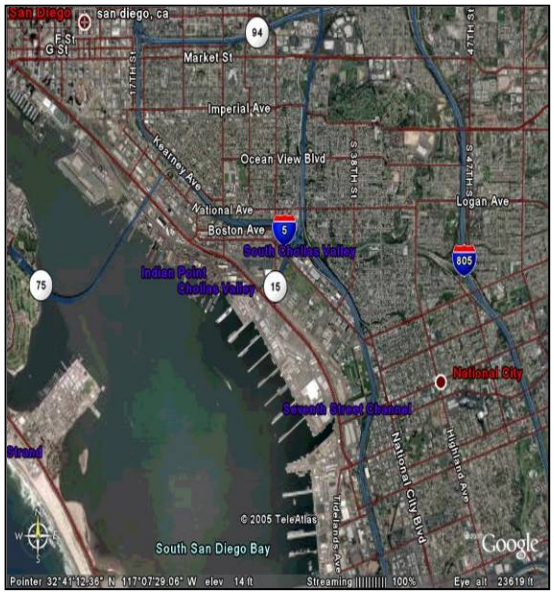

Figure 7. San Diego, CA site.

Figure 8. Quay wall between Piers 1 and 2, San Diego.

5.2 PRESENT OPERATIONS

SSP, including Bulkhead 303 Pensacola and Quay wall Pier 1/Pier 2 San Diego, initially received one of two coating system options (shop application under controlled conditions) for steel placed in sea water immersion/splash zones as specified in UFGS – 09967 Coating of Steel Waterfront Structures. The coating systems are either three coats epoxy-polyamide or two coats coal tar epoxy-polyamide. Both systems are historically known to provide approximately five years of splash zone service before maintenance is required. Maintenance can be localized surface prep and recoat to complete removal and reapplication. However, historically sheet piles are typically allowed to corrode in place with no coating maintenance employed due to the high cost and environmental concerns that have to be addressed. In addition, neither of these systems is suitable for in-service field maintenance. Therefore, DoD activities typically contact a protective coatings consultant (NAVFAC Paints/Coatings Center of Expertise) for the latest untested state-of-the-art commercial recommendation. It follows that field activities continue to require a coating system capable of in-service field maintenance such as the current SZCs under demonstration.

5.3 SITE-RELATED PERMITS AND REGULATIONS

The industrial painting contractors were required to comply with Federal, state, and local environmental regulations throughout all aspects of the surface preparation and coating application as further defined in the following sections of the installation contract.

All surface preparation liquid and paint debris waste was contained, collected, stored and analyzed for hazardous material concentrations prior to appropriate disposal. The following guide specification sections from the demonstration plan installation contract address these issues.

1. Section 01525 "SAFETY AND OCCUPATIONAL HEALTH REQUIREMENTS" and Section 13283N "REMOVAL/CONTROL AND DISPOSAL OF PAINT WITH LEAD" (where applicable) were part of the demonstration contract and forms the demonstration site "Health and Safety Plan." These Sections are currently titled UFGS 01 35 29 "SAFETY AND OCCUPATIONAL HEALTH REQUIREMENTS" and UFGS 02 82 33.13 20 "REMOVAL / CONTROL AND DISPOSAL OF PAINT WITH LEAD". To ensure additional "Health and Safety Plan" compliance, the industrial painting contractor was certified by the SSPC to:
   - SSPC QP-1 "Standard Procedure for Evaluating the Qualifications of Painting Contractors Performing Industrial Surface Preparation and Coating Application in the Field."
   - SSPC QP-2 "Standard Procedure for Evaluating the Qualifications of Painting Contractors to Remove Hazardous Paint."
2. Section 01572 "CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT,"
3. Section 01575N "TEMPORARY ENVIRONMENTAL CONTROLS,"

4. Section 01770N “CLOSEOUT PROCEDURES,”
5. Section 02120A “TRANSPORTATION AND DISPOSAL OF HAZARDOUS MATERIALS,” and,
6. Section 09967 “COATING OF STEEL WATERFRONT STRUCTURES.”

Local and Federal environmental permits associated with construction work were required. These will likely change over time. At the very least a base may require an approved notice of intent (e.g., regional waste water discharge), environmental plan, and a site-specific safety plan.

6.0 TEST DESIGN

The full-scale demonstration experimental design is essentially the same as the demonstration performance objectives, demonstration performance criteria, expected performance, and performance confirmation methods including National Transportation Product Evaluation Program (NTPEP) testing, as presented in Table 3. Data collection methods followed a combination of requirements set by industry standards (American Society for Testing and Materials [ASTM], SSPC, etc.). Preliminary requirements and a sequential list of events are further developed in the full report.

The year one through year four SZC field performance monitoring and assessment reporting were performed in accordance with "Primary Criteria" as presented in Table 4, headings "One Year Field Performance" and "Four Years Field Performance."

6.1 LABORATORY TESTING

Laboratory testing of the SZC under the American Association of State Highway and Transportation Official's (AASHTO) NTPEP for "Structural Steel Coating Systems" employing AASHTO Standard Practice R 31-02 consists of the performance criteria as defined in Table 3 "Laboratory Performance Metrics with Confirmation Methods," below.

Table 3. Laboratory performance metrics with confirmation methods.

Performance Criteria	Expected Performance Metric	Performance Confirmation Method
Primary Criteria (Quantitative)		
NTPEP SZC Testing - R 31-02		
Formula		
Color	Property documented	Fed. Std. 595, ASTM D 2244
VOC	No more than 50 g/L	ASTM D 2369
Total solids (weight)	Property documented	ASTM D 2369
Total solids (volume)	Property documented	ASTM D 2697
Percent pigment	Property documented	ASTM D 2371
Stormer viscosity	Property documented	ASTM D 562
Brookfield viscosity	Property documented	ASTM D 2196
Pot life	Property documented	NA
Sag resistance	No less than 7 mm	ASTM D 4400
Theoretical coverage	Property documented	NA
Drying times	Properties documented	ASTM D 1640
Mixing ratio	Property documented	NA
Shelf life	Property documented	NA
Infrared analysis	SZC fingerprint	NA
Heavy metals	Free of chromium and lead	ASTM D 3335
Dry film leachable metals	Free of arsenic, mercury, and silver	TCLP[a]/EPA SW 846
Epoxide value	Property documented	ASTM D 1652
Amine value	Property documented	ASTM D 2073
Laboratory Performance		
4000 hr salt fog resistance	Performance documented	ASTM B 117, ASTM D 1654
336 hr cyclic weathering	Performance documented	ASTM D 5894
Abrasion resistance	Performance documented	ASTM D 4060
Adhesion testing	Values documented	ASTM D 4541
30 day freeze thaw stability	Performance documented	AASHTO R 31-02

6.2 FIELD TESTING

A combination of laboratory and field performance data is mandatory since laboratory testing seldom reflects field performance and field performance rarely duplicates accelerated laboratory weathering. With the successful meeting of the criteria for one-year field performance (see Table 4), the results were combined with the NTPEP product testing to develop a SZC formula/laboratory performance based standard. As such, NTPEP product testing data did support full-scale field demonstration data and provided additional SZC data for use in baseline comparisons.

Table 4. Field performance metrics with confirmation methods

Performance Criteria	Expected Performance Metric	Performance Confirmation Method
Primary Criteria (Quantitative)		
Pre-Demonstration – Coating Condition Survey		
Corrosion	No more than 30% metal loss	ASTM D 610 (% of total surface area)
Peeling	No more than 15% peeling	ASTM D 610 (% of total surface area)
Blistering	No more than 15% blistering	ASTM D 610 (% of total surface area)
Tape adhesion	Document adhesion	ASTM D 3359 (>3 tests)
Pull-off adhesion	Document adhesion	ASTM D 4541 (>3 tests)
Film thickness	No more than 20 mm	ASTM D 4138, SSPC PA-2
Metal thickness	At least 0.25 in	Metal thickness gauge
SZC patch test adhesion	More than 450 psi and >4A	ASTM D 3359, D 4541 (3 tests)
One-Year Field Performance		
Corrosion	No more than 0.1% corrosion	ASTM D 610 (% of total surface area)
Peeling	No more than 0.1% peeling	ASTM D 610 (% of total surface area)
Blistering	No more than 0.1% blistering	ASTM D 610 (% of total surface area)
Tape adhesion	No less than 4A	ASTM D 3359 (>3 tests)
Pull-off adhesion	More than 450 psi	ASTM D 4541 (>3 tests)
Film thickness	Report thickness	ASTM D 4138, SSPC PA-2
Cracking/checking	No less than 8	ASTM D 660, ASTM D 661
Chalking	No less than 8	ASTM D 4214 (% of total surface area)
Biological growth	No less than 8	ASTM D 3274 (% of total surface area)
Dirt pick-up	No less than 8	ASTM D 3274 (% of total surface area)
Four-Years Field Performance		
Corrosion	No more than 0.3% corrosion	ASTM D 610 (% of total surface area)
Peeling	No more than 0.3% peeling	ASTM D 610 (% of total surface area)
Blistering	No more than 0.3% blistering	ASTM D 610 (% of total surface area)
Tape adhesion	No less than 3A	ASTM D 3359 (>3 tests)
Pull-off adhesion	More than 110 psi	ASTM D 4541 (>3 tests)
Film thickness	Report thickness	ASTM D 4138, SSPC PA-2
Cracking/checking	No less than 8	ASTM D 660, ASTM D 661
Chalking	No less than 8	ASTM D 4214 (% of total surface area)
Biological growth	No less than 8	ASTM D 3274 (% of total surface area)
Dirt pick-up	No less than 8	ASTM D 3274 (% of total surface area)

Table 4. Field performance metrics with confirmation methods (continued)

Performance Criteria	Expected Performance Metric	Performance Confirmation Method
Secondary Criteria (Qualitative)		
Factor affecting technology performance	Level of surface preparation equal for all three coatings	Document operator experience and/or on-site training [in notebooks]
Reliability	Reliability higher than routine maintenance painting employing traditional coating materials	Document installation sequence and QA/QC processes including those for the control coating [in notebooks]
Ease of use	Contractor friendly	Document operator experience and report operator comments [in notebooks]
Maintenance	Reduction in scheduled maintenance cycles	Document one and four year field performance as compared to the control [first year complete]
Scale-up constraints	Demonstration performed at full-scale using COTS surface preparation and SZC application equipments	Document operator experience and/or on-site training, installation sequence and QA/QC processes [no need to document]
Reduced painting operations debris/waste	25% reduction	Document/report collection/disposal wastes [in notebooks]
Reduced hazardous materials	95% hazardous material reduction	Compare/calculate against coatings employed in UFGS 09 97 13.26 [comparison of formulations]

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7.0 PERFORMANCE ASSESSMENT

7.1 LABORATORY TESTING

Table 5a shows the pre-demonstration coating condition survey results for both the Pensacola and San Diego demonstration sites. Since the expected performance metric for the existing Pensacola coating was not met (Table 5a), the sea wall surfaces (Figure 9) were prepared by water blasting followed by grit blasting (Figure 10). This assured adequate adhesion of the applied coatings (Table 5b). The surface in San Diego (Figure 11) was prepared for remedial coating by water blasting only (Figure 12). Metal thickness was measured to ensure enough metal remained to make remedial coating worthwhile and as a baseline to determine any long-term corrosion as indicated by metal thickness loss.

Table 5a. Pre-demonstration survey results: Expected performance metrics and actual performance at Pensacola and San Diego test sites.

Performance Criteria	Expected Performance Metric	Actual Performance	
		Pensacola	San Diego
Existing Coating Condition Survey			
- Corrosion	≤30% metal loss	~3/8 inch avg. rust scale	3/24/05 notes: 7% coating failure; 5% corrosion; 20% metal loss at pits max.; 12% metal at coating failure.
- Peeling	≤15% peeling	65-90%	
- Blistering	≤15% blistering	70-90%	
- Tape adhesion	NA	3A-4A	
- Pull-off adhesion	NA	95 psi avg.	
- Film thickness	≤20 mm	7-30 mm	
- Metal thickness	≥0.25 in	1999 report: ~38% max. metal loss at web; web 0.25-0.32 in; ~8% metal loss at flange; 0.46-0.54 in 10/12/06 tests: 0.524-0.530 in outer, 0.276-0.387 in angle, and 0.489-0.517 in inner	

Table 5b. Pre-demonstration survey results: Expected performance metrics and actual patch test performance at Pensacola and San Diego test sites.

Performance Criteria	Expected Performance Metric	PCS[a]	PR[b]	PS[c]
Pensacola Patch Tests				
SZC patch adhesion	>450 psi >4A	290 psi avg. 5A	398 psi avg. 4A-5A	486 psi avg. 5A
San Diego Patch Tests				
SZC patch adhesion	>450 psi >4A	243 psi avg. 5A	380 psi avg. 3A-5A	435 psi avg. 5A

[a]Premier Coating Systems: PCS #1200TA
[b]Polymeright: CP Chem TZ-R 904
[c]PolySpec: Thiokol LPE 5100 Splash Zone Coating

Figure 9. Typical corrosion on Pensacola steel sheet pile before surface preparation.

Figure 10. Pensacola steel sheet pile surface preparation.

Figure 11. Typical corrosion on San Diego steel sheet pile before surface preparation.

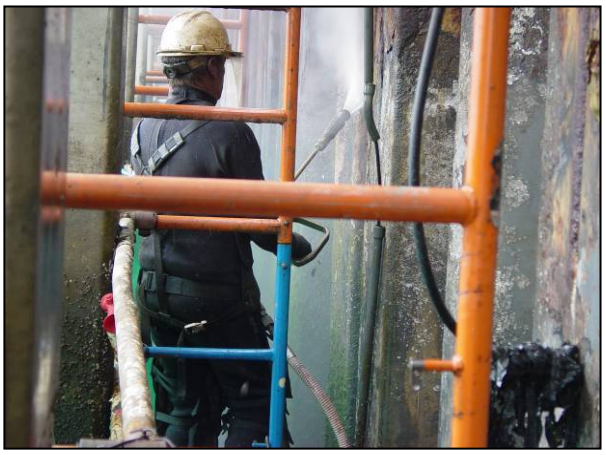

Figure 12. San Diego steel sheet pile surface preparation.

The most critical data of Table 5 are the SZC patch adhesion results (Figures 13 and 14). The patch test coatings were applied within an hour after blast cleaning but flash rust occurred within

20 min after blasting (Figures 15, 16, 17, and 18). In both Pensacola and San Diego the control coating (PCS #1200TA) performed somewhat poorly with low adhesion (290 and 243 psi, respectively). This is in contrast to the test coatings of Polymeright (398 and 380 psi, respectively) and Polyspec (486 and 435 psi, respectively). Only the Polyspec product in Pensacola met the expected performance metric. Since a coating's adhesion to a substrate typically reflects degree of surface preparation and is generally a very good indicator of long-term coating performance, this patch test bodes well for the future performance of the Polyspec test coating.

Figure 13. Typical test patch – Premier coating system on Pensacola steel sheet pile.

Figure 14. Typical test patch – PolySpec coating on San Diego steel sheet pile.

Figure 15. Typical appearance of Pensacola SSP just after surface preparation.

Figure 16. Pensacola SSP after flash rusting and before coating application.

Figure 17. Typical appearance of San Diego SSP just after surface preparation.

Figure 18. San Diego SSP after flash rusting and before coating applications.

After successful patch tests, surface preparations and coating applications were completed in both San Diego and Pensacola. In contrast to the patch test coatings which were applied within an hour of surface preparation, the full coatings were applied hours to days after cleaning (Figures 19 and 20).

Figure 19. Coating application on Pensacola SSP.

Figure 20. Coating application on San Diego SSP.

7.2 FIELD TESTING

Table 6 provides the final one year coating condition survey results along with the expected performance metrics and actual performance at both the Pensacola and San Diego test sites. This information provides a means to compare the metrics and costs.

Table 6. One year coating condition survey results: Expected performance metrics and actual performance at Pensacola and San Diego test sites.

Performance Criteria	Expected Performance Metric	Actual Performance					
		Pensacola			San Diego		
		PCS[a]	PR[b]	PS[c]	PCS[a]	PR[b]	PS[c]
Corrosion	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%
Peeling	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%
Blistering	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%	≤0.1%
Tape adhesion	≥4A[d]	NA	NA	NA	NA	NA	NA
Pull-off adhesion	>450 psi[d]	NA	NA	NA	NA	NA	NA
Film thickness	NA	NA	NA	NA	NA	NA	NA
Cracking/checking	≤8	≤8	≤8	≤8	≤8	≤8	≤8
Chalking	≤8	≤8	≤8	≤8	≤8	≤8	≤8
Biological growth	≤8[e]	≤8, NI	≤8, NI	≤8, NI	≤8, NI	≤8, NI	≤8, NI
Dirt pick-up	≤8	≤8	≤8	≤8	≤8	≤8	≤8

[a]Premier Coating Systems: PCS #1200TA
[b]Polymeright: CP Chem TZ-R 904
[c]PolySpec: Thiokol LPE 5100 Splash Zone Coating
[d]Both are destructive tests and not performed
[e]No impact on the coating system/substrate

First year survey report attached as Appendix C in Final Report.[15]

The Primary Criteria (quantitative) for one-year field performance from Table 4 were met thereby leading to the use of the NTPEP Secondary Performance Criteria (quantitative) to develop a SZC formula/laboratory performance based standard. It is anticipated, based upon small-scale field demonstrations of the SZC, that much more than a minimum of one-year field performance will be achieved. As such, NTPEP laboratory data supported by actual field performance have been used to transition the data into a new SZC commercial standard for use in amending UFGS 09 97 13.26 "Coating of Steel Waterfront Structures." At this time the UFGS has been amended to include the requirements for the SZC until the standard is finalized. The UFGS has been completed and is in the process of being vetted through the responsible agencies.

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8.0 COST ASSESSMENT

8.1 COST MODEL

The primary objectives of the detailed cost model is to document, develop, and validate the expected costs of implementing a real-world SZC painting option for use on multiple SSP and/or steel waterfront structures requiring additional corrosion protection utilizing environmental compliant coatings. Direct and indirect SZC full-scale field demonstration costs were documented and analyzed using a combination of cost assessment tools such as Impact Analysis[16], the Environmental Cost Analysis Methodology (ECAM), trade industry estimating guidance[17, 18, 19], field activity based costing methodology, and the tracking of actual demonstration costs, including direct line item submittal costs from the SZC installation contractor.

However, after all the labor intensive cost assessment work is complete, custodians of steel waterfront structures requiring maintenance painting will decide whether to employ the environmentally compliant SZC based primarily on a comparison of the Cost Per Unit Area (CPUA) supported by the anticipated years of service. Results must then be compared directly to costs and performance associated with waterfront structure removal and a new waterfront structure installation.

First, the actual full-scale field demonstration costs were reported followed by estimated costs associated with annual SZC maintenance painting of multiple SSPs. For example, direct costs for activity funded SZC field painting can include the containment system, wastewater and paint debris collection/treatment/disposal, environmental monitoring, total surface area requiring welded metal spot repairs (repairing holes in SSP), number of workers and worker hours per stage of work, labor hours including benefits, material costs, equipments costs, overhead costs, and several others. All indirect environmental cost and other costs were identified, reported, and subsequently evaluated.

The following information is taken from the contracts let to accomplish the work at both locations.

$120,000 contracts each to Polymeright and PolySpec extended to September 2006 for San Diego work only.

San Diego

- $345,000; contract to Techno Coatings for San Diego Demonstration – administered through S&K Technologies.
- $46,000; QA/QC performed by Dave Gaughen.

$391,000 Total Project Cost for 700 LF
$37.60 per SF based on total surface area of 10,400 SF.

Pensacola

- 06/2005
  - $236,500; contract to Madcon Corp. subcontract to Ellis Environmental.
- 9/15/06
  - $336,000; total revised actual cost, includes modifications due to delays.
  - $151,000; QA/QC performed by Dave Gaughen.
  - $166,000; direct support of Madcon expenses by NFESC.

$653,000 Total Project Cost for 700 LF
$44.42 per SF based on total surface area of 14,700 SF.

Table 7 will be used to report costs for the SZC.

Table 7. Examples of types of costs by category.

Direct Environmental Activity Process Costs							
Direct Start-Up Costs		**Direct Operation & Maintenance**		**Indirect Environmental Activity Costs**		**Other Costs**	
Activity	**$**	**Activity**	**$**	**Activity**	**$**	**Activity**	**$**
Equipment purchase	0	Labor to operate equipment	0	Compliance audits	0	Overhead assoc. with process	1K
Equipment design	0	Labor to manage hazardous waste	0	Document maintenance	1K	Productivity/ cycle time	0
Mobilization	0	Utilities	2K	Environ management plan development & maintenance	0.5K	Worker injury claims & health costs	0
Site preparation	0	Management/treatment of by-products	0	Reporting requirements	0		
Permitting	0	Hazardous waste disposal fees	0	Test/analyze waste streams	0		
Training of operators	0	Installation[a] • surface preparation • material costs • paint application • containment • disposal • environ. monitoring • worker health • labor • overhead/misc. • tools/equipment • other	198K	Medical exams (including loss of productive labor)	0		
		Process chemicals, nutrients	0	Waste transportation (on- and off-site)	0		
		Consumables and supplies	0	OSHA/EHS training	0		
		Equipment maintenance	0				
		Training of operators	0				

aOne-time painting contractor installation costs per 10,000 SF of SSP; cost represents a lump sum figure that includes all materials, coating installation, and waste disposal fees.

8.2 COST ANALYSIS AND COMPARISON

For cost comparative purposes the following information is provided as to a full-scale repair to a facility. Whereas the costs for the present project ranged from $50 to less than $100 per SF, some of the more extensive projects noted below had costs exceeding $100 per SF to more than $130 per SF assuming an 18 foot tall splash zone.

Wake Island Fueling Pier Repair Cost Estimate – September 2005
Steel Sheet Piling Splash Zone Coating = $396,000 for 205 LF bulkhead x 12.7 ft (MLLW to top of sheet piling).
Total actual surface area about 4090 SF = **$96.82 per SF** (about 50% of cost attributed to remote location).

Naval Station San Diego – August 21, 2001
Contract award of $8,745,173 firm-fixed-price contract for the temporary shutdown/repair of the Paleta Creek Fendering System and Quay wall at Naval Station San Diego. Work was performed in San Diego, Calif., and was completed by September 2003.
LF = ~3,150 Cost for Quay wall Repair only ~$6.5 million = **~$2,063 per LF**

Naval Station San Diego – September 24, 2003
Contract award of $16,770,000 firm-fixed-price contract for repair of Chollas Creek Fender System and Quay wall at Naval Station San Diego and Fender Piles (Phases I and II) at Naval Amphibious Base Coronado. Sheet Pile Installation in front of existing concrete sheet piles, includes new concrete cap, some repairs to existing concrete. New sheet piling coated with coal tar.
LF = ~ 4,720 Cost for Quay wall Repair only ~ $11.5 million **= ~$2,436 per LF**

A cost comparison should be performed to evaluate the environmentally compliant SZC as compared to complete structure removal/new structure installation employing coatings similar to those specified in UFGS 09 97 13.26, and potentially compared to emerging coatings at multiple sites throughout the Navy. This cost comparison was not performed as it was outside the scope of the project. When performed, the comparison should take into consideration the annual economic and environmental considerations of the proposed alternative versus the existing process.

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9.0 IMPLEMENTATION ISSUES

9.1 ENVIRONMENTAL CHECKLIST

The painting contractors are required to comply with Federal, state, and local environmental regulations throughout all aspects of any full-scale demonstration or follow-on work that deals with removal of old splash zone coatings and the application of new coatings. The reader is directed to section 4.3, Site-Related Permits and Regulations, for an outline of relevant items.

9.2 OTHER REGULATORAY ISSUES

A regulatory representative from either the SCAQMD of California at Los Angeles or a southern California district representative of EPA, or both, should be contacted for participation in any project demonstration in San Diego.

9.3 END-USERS/ORIGINAL EQUIPMENT MANUFACTURERS (OEM) ISSUES

Concerns, reservations, and decision-making factors affecting SZC buy-in from DoD end-users have been reviewed by technical POCs from the Navy, Army and Air Force and are providing guidance documents in advance of submission to NAVFAC's Engineering Innovative Criteria Office (EICO) for guidance inclusion on the Construction Criteria Base's (CCB) web site at http://www.ccb.org. The full-scale SZC demonstration(s), including the NTPEP testing, will confirm acceptable SZC performance prior to drafting new DoD guidance.

PolySpec L.P. has annual sales in excess of $10 million and large volume production, including international sales and distribution to locations outside the continental United States. Polymeright, Incorporated has developed a joint partnership for coating commercialization with Chevron Phillips Chemical Company LP, a multi-billion dollar international corporation. As such, manufacturing including SZC distribution is not a significant concern.

Procurement of the SZC will be specified in the amended UFGS using a combination of performance and formulation properties. A new MPI DPS will be developed to replace the SZC specification language. Referencing either the new MPI DPS or presenting formulation and performance testing requirements within the new specification is sufficient to enable other coating manufacturer's to compete for SZC sales and eliminates the requirement of sole source SZC procurement. As such, SZC procurement will then become a required contractor's material submittal when preparing a bid for work to perform corrosion control on an SSP requiring maintenance painting.

To reiterate, demonstration results are being transitioned into commercial guidance such as a new MPI DPS for the SZC followed by amending UFGS entitled "Coating of Steel Waterfront Structures." The DPS and the UFGS will be web-displayed at http://www.paintinfo.com, http://www.ccb.org/ufgs/ufgs.htm, respectively, and for direct use by Tri-service activities with aboveground storage tanks (AST) in need of maintenance painting. In addition to the above, PolySpec L.P. and Polymeright, Inc., will continue to produce and market the SZC to the original equipment manufacturer (OEM) community including the Bureau of Reclamation and to state

Departments of Transportation (DOT). Other applications of the SZC may include bridges, offshore structures, structural steel, antenna towers, and various concrete structures.

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APPENDIX A
POINTS OF CONTACT

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