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# THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

## Evaluation of New Surface Preparation and Coating Repair Techniques in Ballast Tanks - Phase IV

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Halter Marine Group, Inc.

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# EVALUATION OF NEW SURFACE PREPARATION AND COATING REPAIR TECHNIQUES IN BALLAST TANKS-PHASE IV

# TWENTY YEARS OF BALLAST TANK COATING SYSTEM TESTING

**NSRP 3-96-2**

September 2000

**PREPARED BY:**
**ASSOCIATED COATINGS CONSULTANTS, INC.**
**IN COOPERATION WITH**
**HALTER MARINE**
**GULFPORT, MS**

## FOREWORD

The research objective of this project is to test and evaluate maintenance and repair techniques, which can be used to reduce the life cycle cost of maintaining coating and lining systems in ships ballast tanks. This test program is a continuation of a ballast tank coatings test program which first began in 1980 as a new construction project and was entitled "Cathodic Protection/Partial Coatings Verses Complete Coatings in Tanks." In 1988, the test program was redirected to evaluate maintenance procedures and techniques. During the intervening twenty years of testing, numerous approaches to corrosion control have been investigated to both reduce cost and in more recent years, be environmentally friendly.

One of the major findings of these studies has been the importance of cathodic protection in extending the life of tank coating systems. There is a synergistic relationship between coating systems and cathodic protection. To achieve a perfect pinhole free, uniform paint film is both difficult and expensive. In ballast tanks this difficulty is amplified due to the complex tank geometry. Numerous sharp edges exist throughout the tank because of lighting holes, weep holes for drainage, and internal "T" bar structures. Cathodic protection in the form of sacrificial anodes provide corrosion protection to all bare areas in the tank; whereas, the existence of a sound coating reduces the demand on the anode, thus increasing anode life. The existence of a sound coating system also helps to spread the passivating, protecting current more uniformly over the surface of the tank. As the bare areas are passivated, calcareous deposit forms which acts as a barrier, further reducing anode demand. As the coating fails with time, this process is repeated.

There are three coating systems in this project, which utilize coatings combined with cathodic protection that have provided corrosion protection for twenty years. Another system, which consisted of a thin film, pre-construction zinc primer with zinc anode, lasted for eleven years. A full thickness, solvent based inorganic zinc with a sacrificial zinc anode is providing excellent protection after seven years of testing when applied over a surface highly contaminated with salt.

This NSRP Program has provided both volumes of valuable performance data on coating system performance plus has acted as a catalyst to promote open technical discussions between the various shipyards and other participants of the marine industry. No other meagerly funded program has developed such a wealth of coating system performance information covering the highly corrosive environment of ships ballast tanks.

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## EXECUTIVE SUMMARY

Ballast tanks are one of the most costly areas in which to provide corrosion control alternatives in both new ship construction and ship maintenance. Being subjected to intermittent wet and dry cycles of aerated seawater places extreme demand on corrosion control methods. Harsh service environments are coupled with necessarily complex tank geometries, especially in Navy combatants where weight and hull designs dictate small, irregular tanks with difficult accessibility. This research project was formulated to investigate alternative, environmentally acceptable, cost-effective corrosion control solutions for ships ballast tanks.

The first project began in 1980 and was entitled "Cathodic Protection/Partial Coatings Versus Complete Coating in Tanks." A series of steel ballast tank mock-ups were constructed which duplicate tank geometries. The tanks are large enough to allow access for surface preparation and installation of the various corrosion control methods. The initial program included:

- High performance epoxy, ballast tank coating system (Mil-P-23236 Qualified). Tank was completely coated.
- Sacrificial cathodic protection plus partial coating (high performance epoxy, Mil-P-23236 Qualified). Top and bottom of tank coated; center section was left bare. One tank was fitted with zinc anode, and the other tank was fitted with aluminum anode.
- Soft coating plus cathodic protection.
- Pre-construction, zinc rich primer with and without sacrificial cathodic protection.
- Both zinc and aluminum anodes were tested.

At the end of the first five years of testing, the following results were tabulated:

- High performance epoxy coated tank (Mil-P-23236 Qualified) was graded as an ASTM 610 Rust Grade six (1% failure) at the end of five years.
- Partial coatings with sacrificial cathodic protection provided adequate corrosion protection.
- Soft coatings with cathodic protection failed in 90 days - three ballast test cycles.
- Pre-construction, zinc rich primer with zinc anode far exceeded the predicted performance. The system was still providing protection at the end of five years. The system continued to provide protection for ten total years prior to failure and subsequent replacement with an alternate coating.
- Pre-construction primer with aluminum anode failed in three years.
- Zinc anodes outperformed aluminum anodes. Both anodes exceeded predicted system design life.

In 1988, the project was redirected to evaluate maintenance procedures and techniques. At that time, the tanks had been under test for eight years. In 1990, funding was approved to continue the testing through December of 1992. In April 1991, one failed system was replaced with waterborne inorganic zinc, and one surface tolerant epoxy system was repaired. The results of this portion of the program were reported in early 1993 (NSRP 0369).

In 1993, the project was extended for an additional three years. In April of that year, one of the proprietary VOC compliant epoxy tank coating systems was extensively repaired in two of the tanks. One of these tanks was power (SSPC SP-3) and hand tool (SSPC SP-2) cleaned and the other was sweep-blasted (SSPC SP-7). The second proprietary VOC compliant epoxy only required minor repairs. The Navy Formula 150/151 system was also repaired using hand tool cleaning techniques and a refresher topcoat added. Two new VOC compliant solvent based inorganic zinc primers were added to the program; one with a zinc anode and one without. Included in this new project approach were:

- Volatile Organic Compound (VOC) compliant, surface tolerant epoxies from two suppliers. Both hand tool cleaning and abrasive blasting surface preparation techniques were evaluated.
- Mil-P-24441 (Formula 150/151), Type IV, VOC compliant epoxy.
- Biodegradable soft coating.
- A Japanese technique of adding a zinc anode (for cathodic protection) to an existing partially failed coating in lieu of coating replacement.
- A waterborne, high ratio, full thickness inorganic zinc.
- Solvent-based, VOC compliant, full thickness inorganic zinc with and without cathodic protection.
- Two coating systems from the original project were still providing adequate protection and, therefore, left undisturbed.

After three years of testing under the new program the following results were reported:

- One of the VOC compliant surface tolerant epoxy coating systems was essentially equal in performance when applied over either hand tool cleaned or abrasive blast cleaned surfaces.
- Excessive film thickness of one of the surface tolerant epoxies partially failed due to high film thickness in some areas.
- The VOC compliant version of Mil-P-24441 provided good corrosion protection. Most areas of failure could be attributed to poor application.
- Biodegradable soft coating failed in less than one year.
- Zinc anode addition to six-year-old, totally coated tank (Mil-P-23236) was providing adequate protection at the end of the eight-year test period without any repairs being made to the existing coating system.
- The waterborne, high ratio, full thickness inorganic zinc was providing adequate protection.

An update report was published in 1996. At this time, one of the surface tolerant epoxies that was applied over the sweep blast cleaned surface had slightly better performance than the same system applied over the hand and power tool cleaned surface. The second surface tolerant epoxy was still providing adequate protection after eleven years of testing. This system was repaired at six and eight years. The VOC compliant version of Mil-P-24441, Type IV, was also continuing to protect the steel substrate after eight years. The waterborne, high ratio inorganic zinc was beginning to fail in five years. Both the solvent-based, inorganic zinc coating systems, with and without CP were still providing excellent protection.

As will be discussed in this report, the surface tolerant epoxy applied over the sweep blast cleaned surface outperformed the same material applied over a hand and power tool cleaned surface. The high ratio, waterborne inorganic zinc totally failed after nine years. The solvent-based, VOC compliant inorganic zinc with the zinc anode is providing excellent protection after seven years and is much better than the same system without the cathodic protection (CP). The fully coated tank with added zinc anode (early version Mil-P-23236) is still providing adequate protection. The partially coated tank with CP lost one-half the section thickness in the bare areas.

As will be further discussed in the body of this report, this program has provided invaluable performance data on several approaches to corrosion control measures, which can be applied to ships ballast tanks. Table 2 contains a listing of all the systems presently being evaluated. Previous NSRP Reports include 0158, 0205, 0280, and 0332.

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## CONCLUSIONS

This report includes the controlled testing results of seventeen different approaches to surface preparation and coating repair techniques for preservation of in-service ships ballast tanks utilizing VOC compliant coatings after twenty years of testing.

The project was originally initiated to test and evaluate the technical feasibility and economics of using a combination of cathodic protection and partial coatings in lieu of complete coatings of new construction ballast tanks. Mock-up test tanks were constructed and coated to verify performance. To simulate ballasting and de-ballasting during ship operations, the test tanks were ballasted full with salt water for twenty days and then drained and left dry for ten days. This cycle has been repeated for the entire test duration.

In recent years, the investigation shifted to determining the technical feasibility of reducing coating repair costs utilizing surface tolerant materials in combination with less costly surface preparation techniques, i.e., hand and power tool cleaning, with special emphasis given to VOC compliant coatings. Emphasis also included retention of as much of an existing sound coating, as possible, when performing protective coatings maintenance. As an example, in lieu of complete removal and replacement of the partially failed Mil-P-24441, Type IV coating system, the system was spot repaired using a combination of hand and power tool cleaning, spot primed, and a complete refresher coat applied. Likewise, Sweep Blast Cleaning was substituted for complete removal via abrasive blasting when repairing one of the surface tolerant epoxy systems.

Because of the excellent performance of a single coat of inorganic zinc pre-construction primer combined with cathodic protection, a VOC compliant, single coat, alkyl silicate, inorganic zinc coating system with and without cathodic protection was selected for testing.

At the end of twenty years of testing, the test results can be summarized as follows:

- The Surface Tolerant Epoxy "A" applied over the abrasive Sweep Blast Cleaned (SSPC SP-7) surface provided better corrosion protection than the same system applied over a hand tool cleaned surface. Both systems have been under test for twelve years, with an intermediate repair being accomplished at five years.

- The Surface Tolerant Epoxy "B" system ,initially applied over a Commercially Blast Cleaned (SSPC SP-6) surface, provided adequate protection for eleven years with intermediate repairs at six and eight years. Repairs were effected using Hand Tool Cleaning (SSPC SP-2/SP-3) techniques.

- Surface Tolerant Epoxy Coating Systems can provide corrosion protection in ballast tanks for up to six years without major repairs. With repairs scheduled at approximately six-year intervals, the surface tolerant systems can provide long term protection without extensive re-blasting and replacement.

- The VOC compliant version of MIL-P-24441, Type IV (Formula 150/151) provided acceptable corrosion protection to the flat areas for twelve years with interim repairs made at five years; however, the system has total edge failure at the end of the test period. Initial edge failure was reported at the end of three years. Mil-P-24441 also demonstrated surface tolerance to substandard surface preparation.

- The waterborne, high ratio inorganic zinc failed after eight years. This system did not demonstrate compatibility with the salt contaminated substrate.

- The VOC compliant alkyl silicate, inorganic zinc coating systems with and without cathodic protection have very little failure after seven years. The performance of the system with the zinc anode CP has less failure than the system without the added anode. These systems were applied over salt contaminated surfaces.

- Full thickness inorganic zinc coating systems, with sacrificial zinc anodes, have the potential of being a twenty plus year system, even when applied over salt contaminated surfaces.

- Partial coating (Mil-P-23236) with fifty-pound zinc anode system did not provide envisioned protection for twenty years. A reduction of one-half the section thickness in the bare areas was experienced after twenty years.

- Partial coating (Mil-P-23236) with twenty-pound aluminum anode system provided six years of protection.

- Fifty-pound zinc anode addition at the end of the initial six years of exposure, to the totally coated tank (Mil-P-23236), provided extended protection without the necessity of coating repair/replacement for twenty years.

- The use of cathodic protection with coatings compliments and improves the resultant performance of either technique used individually.

- Repair in lieu of total replacement of a coating system is a viable, cost-effective option provided the repairs are accomplished prior to total deterioration of the coating system.

- Zinc anode outperformed aluminum anode based on calculated life verses actual performance.

- With the exception of the inorganic zinc systems and systems with cathodic protection, the major failure mode for organic coating systems was edge failure.

- Microbiological corrosion appears to influence total organic coating system performance.

- Neither of the two soft coatings tested provided long term corrosion protection. One failed by biological attack.

# 1. TECHNICAL BACKGROUND

The original study and test program published in May 1982 with updates in 1985, 1987, 1990, 1991, 1993, and 1996 include detail discussions of various corrosion control techniques. Summarized below are some of the pertinent points of these reports.

## 1.1 Coatings in Conjunction with Cathodic Protection

Sacrificial anode cathodic protection systems can be designed to provide extended protection; however, as the length of protection is increased, the weights of the anodes are necessarily increased. A practical anode weight limit is reached which balances the increased dead weight of the vessel being protected with a reduction of cargo carrying capacity. With naval combatants, increased weight can be more significant. Based on these considerations, anode systems are generally designed to provide four to eight years of protection. In this study, both aluminum and zinc anodes were tested. The twenty-pound aluminum (Galvalum III) anode lasted six years. The fifty pound zinc anode (Mil-A-18001H) lasted thirteen years. The original calculated system life for each type of anode was calculated as being four years.

Sacrificial cathodic protection systems do not provide adequate protection for overhead surfaces due to air pockets. These areas are subject to severe corrosion. Another problem associated with the use of cathodic protection in salt-water ballast tanks is created when the residual water and wet silt accumulate on the tank bottom after de-ballasting. This wet, salt muck provides a path for steel corrosion. Since the anodes are above the surface of the muck, no protection is provided during the de-ballast cycle.

To mitigate these problems, high performance coating systems are generally applied in conjunction with cathodic protection. Coating systems may be applied either to the entire exposed bare area of the tank or application may be limited to the overhead surfaces to include some distance down each bulkhead plus the tank bottom to include some distance above the flat bottom and frames. During ballast, the protective coating system protects the steel and supplements the cathodic protection system, therefore reducing anode consumption. During the de-ballasted portion of the cycle, the coatings protect the high corrosion areas.

Being in natural seawater, the cathodic protection system also causes a calcareous deposit to form over the bare steel areas. This calcareous deposit acts as a protective barrier and reduces the demand and depletion of the anode. Together, the coating and cathodic protection system is complimentary and increases the life of either system used independently.

Generally, cathodic protection is used with barrier coatings such as epoxies; however, sometimes anodes are placed in tanks coated with inorganic zinc. The standard engineering formulas used to calculate anode weight for longevity and anode size for current density and throwing power no longer provide the same degree of accuracy. However, in the absence of empirical data, these standard engineering formulas developed for barrier coatings must still be used as a starting point for determining anode requirements.

Since the surface area of the exposed anode also influences the performance of the anode, it stands to reason that the zinc anode with inorganic zinc coating (85% zinc in the dry film) is complimentary. The zinc coating effectively extends the surface area of the anode thus increasing the current density and throwing power. This point has also been substantiated in the test program as demonstrated by an anode life of thirteen years when used in conjunction with a one mil thick inorganic zinc shop primer. The shop primer was neither repaired after fabrication nor top-coated. All weld areas were bare. There are few other documented case histories of the performance of zinc anode cathodic protection used in conjunction with inorganic zinc coatings.

Because of the difference in aluminum anode potential and zinc rich coatings, these two materials should not be used together. There is generally a rapid depletion of the aluminum anode. This point was verified in the 1980 portion of the test program as reported in 1982.

### 1.2 Volatile Organic Compound (VOC) Compliant Surface Tolerant Coatings

Air quality management standards are progressing to ever more stringent restrictions on both volume and type of solvent based coating systems, which preclude the use of many epoxies and zinc rich tank-coating systems. Coupled with this development are tighter controls over the use of abrasive blasting to clean steel. These abrasive cleaning controls include both air quality requirements for particulate generation during abrasive blast cleaning and spent abrasive residue disposal on site or in landfills. Blast residue disposal costs generally exceed by many orders of magnitude the initial procurement cost of the abrasive. In answer to this challenge, many paint manufacturers have developed new materials which are reported to provide satisfactory performance when applied over less than ideal surfaces, e.g., surfaces which have been hand, power tool, or sweep blast cleaned.

Two VOC compliant, surface tolerant epoxies were tested in this program. Fifteen years ago, one material (Epoxy "B") was initially applied over both a "Commercial Blast Cleaning," SSPC SP-6, prepared surface and a Hand Tool cleaned (SSPC SP-2 and SSPC SP-3) surface. Twelve years ago another material (Epoxy "A") was also applied over hand tool cleaned and sweep blast cleaned surfaces. After eight (Epoxy "B") and five years (Epoxy "A") of testing, both systems required repair. During discussions at the SP-3 Panel meetings, a decision was made that the most appropriate course of action would be to not remove the entire coating systems but to retain all sound coatings. If a portion of the coating is sound and is not replaced, many dollars could be saved in reduced abrasive blast media volume, labor, and materials. This "Fix only what is broke" philosophy is supported by the results of this test program.

### 1.3 Anodes Added to Existing Coated Tank

Some Japanese ship owners utilize a method of extending the useful life of corrosion control coatings which consists of adding zinc anodes in lieu of performing coating system repairs or replacement. During new construction ballast tanks are coated with a high performance coating system. After six to eight years, zinc anodes are added. This has been reported to extend the life of the coating system for another eight to ten years. By replacing anodes as anode depletion occurs, the coating system life can extend for the life of the vessel. In this program, the anode installation in lieu of coatings repair has provided protection for twenty years.

The important points are to replace anodes on a regular basis before major steel failure takes place and to inspect areas with anticipated high corrosion rates, such as overhead and flat bottoms, at regular intervals. Coating systems in these areas may need repair and/or replacement because of the reduced anode effectiveness during de-ballasted cycles as discussed earlier in this report.

The coating system, even if failed as much as twenty-five to fifty percent, reduces anode demand and resultant consumption as compared to a totally bare tank. As the anode causes calcareous deposits to form, anode demand is again reduced, and anode life is extended.

## 2.0 TEST SITE AND TEST TANK CONFIGURATION

### 2.1 Test Site

The test facility was located in Jacksonville, Florida. Following tank fabrication and application of each corrosion control system, the tanks were ballasted with fresh, natural seawater (See Table 2) and then de-ballasted. Each ballast cycle consisted of twenty days full and ten days empty.

**TABLE 1**
**TEST SITE SEA WATER INFORMATION**

| Water Resistivety Ranged From 26 to 29 ohm/cm | SPRING | | SUMMER | | FALL | | WINTER | |
|---|---|---|---|---|---|---|---|---|
| | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX |
| Water Temperature °C | 17 | 20 | 26 | 30 | 17 | 30 | 14 | 25 |
| pH | 6.5 | 7.5 | 7.6 | 8.3 | 6.7 | 8.1 | 7.2 | 8.2 |
| Dissolved Oxygen | 5.8 | 8.5 | 4.2 | 7.8 | 4.2 | 7.6 | 5.2 | 9.4 |
| Salinity (Parts per 1000) | 18 | 29 | 22 | 36 | 6 | 33 | 9 | 27 |

### 2.2 Test Tank Configuration

To verify the relative performance of each corrosion control alternates and the compatibility of cathodic protection anodes with the various coating systems, three ballast tank test assemblies were fabricated from ASTM A-36, 1/4 inch thick hot rolled steel plate and shapes.

The approximate dimensions of each tank assembly are twelve feet long by four feet wide and four feet high. Each tank assembly is divided into three separate test cells for a total of nine test tanks. Each tank assembly is constructed to simulate the internal geometry of an actual ballast tank to include angles, built up frames, "T" bars, and wide flanges. One side of each tank has bolted construction to facilitate access for coating application and inspection. See Figure 1 and Photograph 1.

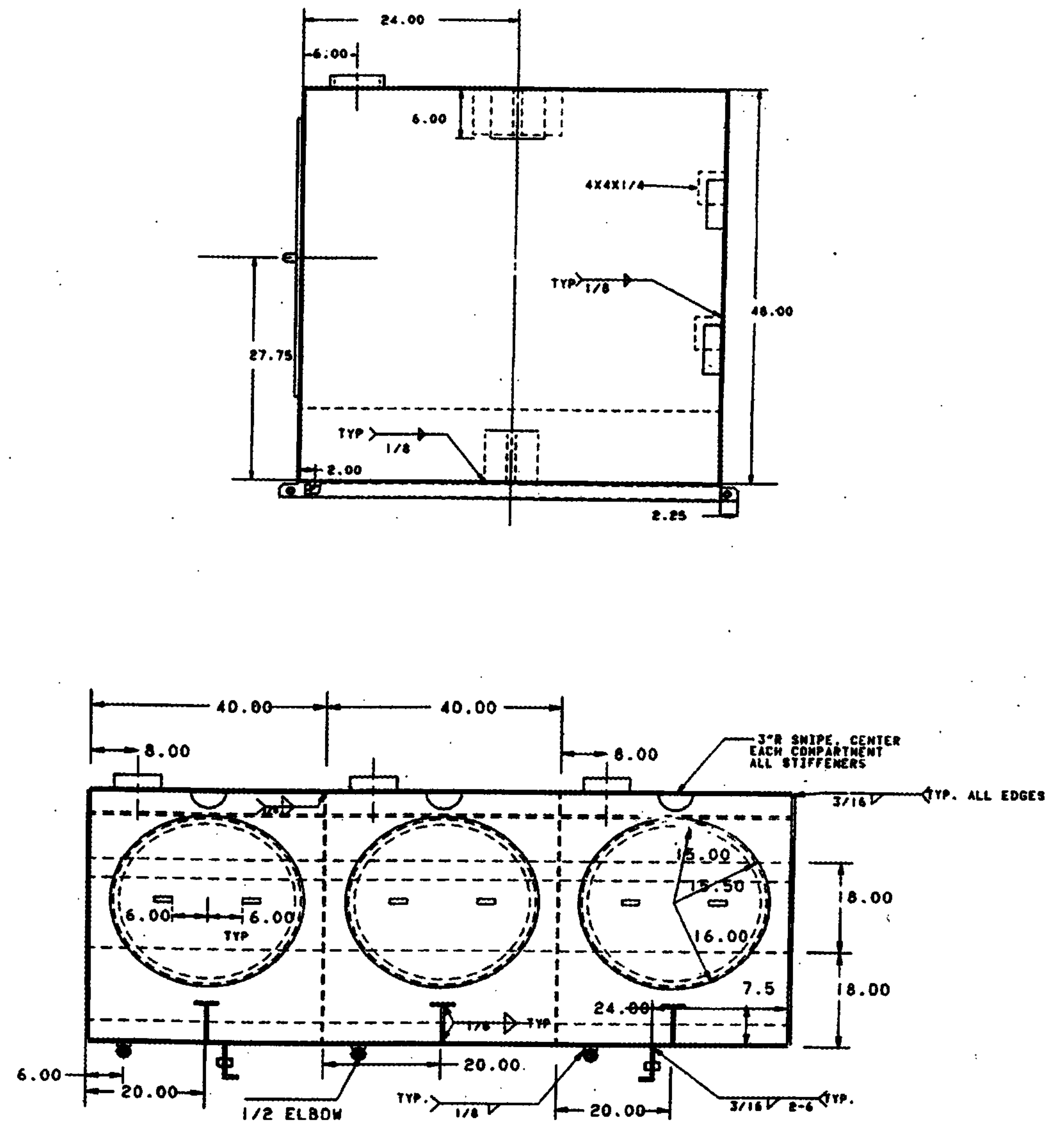



**Figure 1: Drawing of Test Tank Assembly**

## 3.0 SURFACE PREPARATION AND SYSTEM APPLICATION

### 3.1 <u>Surface Preparation</u>

Table 2 contains a listing of the surface preparation of each system under test. Initially all coating systems under test were applied over a Near White Abrasive Blast Cleaned (SSPC SP-10) surface, thus simulating new ship construction. The bare areas in the partially coated tanks also were cleaned to the same degree to remove mill scale, even though no coating system was applied.

Hand (SSPC SP-2) and Power Tool Cleaning (SSPC SP-3) performed during the maintenance portion of the test program consisted of chipping hammers, hand and power wire brushes, and needle guns and power disc sanders. Hand sanding was used to feather the edge of intact remaining coatings. See photograph 2A (Sweep Blast Cleaned) and 2B (Hand & Power Tool Cleaned) for examples of the resultant surface preparation prior to the application Surface Tolerant Epoxy "A."

Photograph 3 shows the repair surface preparation of the Mil-P-24441 system prior to spot priming and full refresher topcoat application.

Abrasive blasting to Near White Cleaning (SSPC SP-10) was used to prepare the surfaces prior to the application of the inorganic zinc coating systems, both the water borne and solvent based systems.

### 3.2 Surface Texture (Profile)

The surface roughness (profile) achieved for the Near White Blast Cleaned surface was 2.2 to 2.5 mils as measured in accordance with ASTM D 4417, Method C.

### 3.3 Surface Contamination

During the maintenance phase of the program, no attempt was made to remove invisible salt surface contamination, as one of the goals was to verify performance over substandard surfaces. A flash rust-back-free surface preparation was not achievable when using abrasive blast cleaning techniques. Due to the high chloride contamination of the corroded steel, the blasted surface would flash rust within a matter of minutes. See Photograph 4. This statement holds true for all the tanks, which were re-blasted for this phase of the project.

The chloride levels were determined to be 5 milligrams per square meter for Near White Blast Cleaned surfaces. This may seem low, based on the fact that the surface preparation flash rusted in a less than four hours; but may be due to the limitation of the swab technique used to determine chloride contamination. Sodium chloride salts bound up as ferric or ferrous chloride and combined with other complex salts could have influenced the solubility of the salts removed. After allowing the solution to set for three hours, the conductance of the solution increased resulting in a revised reading of 15 milligrams per square meter.

The chloride contamination of the Sweep Blast Cleaned (SP 7) surface was measured as being 8 milligrams per square meter. The results of the Sweep Blast Cleaned surfaces are shown in Photograph 3.

### 3.4 Coatings Application

All coatings were applied with conventional pressure pots and spray guns. All welds and sharp edges were stripe coated before the application of the first coat and between coats. See Photograph 5. Sharp edges were not rounded.

**TABLE 2**

**CORROSION CONTROL ALTERNATIVES INCLUDED IN TEST PROGRAM**

| SYSTEM DESCRIPTION | SURFACE PREPARATION | DRY FILM THICKNESS (MILS) | ANODE | SYSTEM AGE | REMARKS |
|---|---|---|---|---|---|
| Two Coat Epoxy (Mil-P-23236), Partially Coated – Overhead plus six inches down bulkheads and bottom plus six inches up bulkheads. Center section left bare. | SP-10 | 6-10 | Aluminum Alloy (Galvalum III) 20 # | 13 Years | Amine Adduct Cured Epoxy |
| Two Coat Epoxy (Mil-P-23236), Fully Coated | SP-10 | 6.5-8.5 | Zinc Anode (Mil-A-18001H) 50# | 20 Years | Anode added after 6 years of testing. Amine Adduct Cured Epoxy. |
| Two Coat Epoxy (Mil-P-23236), Partially Coated – Overhead plus six inches down bulkheads and bottom plus six inches up bulkheads. Center section left bare. | SP-10 | 6-9.5 | Zinc Anode (Mil-A-18001H) 50# | 20 Years | Anode replaced at 12 years. Coating on Flat bottom replaced at 13 years. Surface tolerant epoxy applied over a SP-2/SP-3 prepared surface. Amine Adduct cured Epoxy. |
| Inorganic Zinc Pre-construction primer applied prior to fabrication | SP-10 | 2.0 | Aluminum Alloy (Galvalum III) 20 # | 3 Years | Damaged areas were left bare and not repaired. |
| Inorganic Zinc Pre-construction primer applied prior to fabrication | SP-10 | 1.75-2.0 | None | 1 Year | Damaged areas were left bare and not repaired. |
| Inorganic Zinc Pre-construction primer applied prior to fabrication | SP-10 | 1.8 | Zinc Anode (Mil-A-18001H) 50# | 11 Years | Damaged areas were left bare and not repaired. |
| Soft Coating Number One with cathodic protection | SP-10 and then allowed to rust prior to coating application. | 7.0 | Aluminum Alloy (Galvalum III) 20 # | 2 Months | Test discontinued at two months due to saponification of the soft coating. |

**TABLE 2**

**CORROSION CONTROL ALTERNATIVES INCLUDED IN TEST PROGRAM**

| SYSTEM DESCRIPTION | SURFACE PREPARATION | DRY FILM THICKNESS (MILS) | ANODE | SYSTEM AGE | REMARKS |
|---|---|---|---|---|---|
| Soft Coating Number One, no cathodic protection | SP-10 and then allowed to rust | 7.0 | None | 2 Months | |
| Soft Coating Number One | SP-10 and then allowed to rust prior to coating application. | 7.0 | Zinc Anode (Mil-A-18001H) 50# | 2 Months | Test discontinued at two months due to saponification of the soft coating. |
| Soft Coating Number Two | Rusty Surface | | None | <1 Year | Test discontinued at three months due to biological attack. |
| Surface Tolerant VOC Compliant Epoxy "A" | SP-2/SP-3 | | None | 12 Years | Repaired after 5 years using the same system applied over SP-2/SP-3 surface prep. Previously Applied Coating on flat overhead not replaced. |
| Surface Tolerant VOC Compliant Epoxy "A" | SP-7 | | None | 7 Years | Repaired after 5 years using the same system applied over SP-7 surface prep. |
| Surface Tolerant VOC Compliant Epoxy "B". | SP-6 | | None | 15 Years | System was SP-2 repaired after 6 years and 8 years of testing. |
| Surface Tolerant VOC Compliant Epoxy "B". | SP-2/SP-3 | | None | 5 Years | Repaired at 3 years. Discontinued after 5 years of testing. |
| VOC Compliant Epoxy Tank Coating, MIL-P-24441, Type IV | SP-10 | | None | 12 Years | Repaired after 5 years with same system. SP-2/SP-3 of failed areas. |
| VOC Compliant Inorganic Zinc | SP-10 | | Zinc 12 # (Mil-A-18001H) | 7 Years | |
| VOC Compliant Inorganic Zinc | SP-10 | | None | 7 Years | |
| High Ratio Waterborne Inorganic Zinc | SP-10 | | None | 9 Years | |

# 4. TEST RESULTS

## 4.1 Evaluation and Grading Methods

### ASTM D-610

Table 3 contains a detail evaluation of each coating system under evaluation. Two grading techniques were used. In the first, ASTM D-610, "Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces" (SSPC Vis 2) was used to determine degree of failure. Each tank was divided into ten different grading areas. These areas include the flats (top, left side, right side, back, and bottom) and structure (top stiffener, top and bottom back stiffener, bottom stiffener, and bottom frame). A numeric grade based on the equivalent ASTM rust grade is assigned to each graded area. Listed below is a comparison between ASTM D 610 rust grade and percent failure.

| ASTM RUST GRADE | PERCENT FAILURE |
| --- | --- |
| 9 | 0.03% |
| 8 | 0.1% |
| 7 | 0.3% |
| 6 | 1.0% |
| 5 | 3.0% |
| 4* | 10.0% |
| 3 | 16.0% |
| 2 | 33.0% |
| 1 | 50.0% |

- Rust grade 4 is generally considered as total failure, which requires repair or replacement.

Table 4 contains the twenty-year performance summary, as graded by ASTM D610, of all the systems evaluated.

### CLER

The second grading technique, which is simpler, more straight forward, and requires less technical training uses the Carrier Life Enhancing Repair (CLER) Aircraft Carrier Tank and Void Inspection Booklet. A CLER rating is given based on a photographic representation of a degree of failure. Each photograph has a numeric value assigned. The best performance is designated as 1, and the worst is designated as 4. The tank is divided into four areas: top, sides, bottom, and "T" bar. Each area is compared to the photographic standard and assigned a number, which most closely matches the photograph. A numeric score is then assigned to the tank based on the sum of the scores of each individual area. Table 5 contains a summary of the results from four different observers using the CLER technique. With the exception of Tank 8, the scores between observers are close.

The American Bureau of Shipping (ABS) published a similar manual in 1995, "Coating Systems – A Guidance Manual for Field Surveyors." This manual uses a rust scale similar to ASTM D 610 except that percentages of failure are reported being with 0.1% with gradations through 50%.

**ASTM F 1130**

A third technique which can be used to evaluate and document tank coating performance is ASTM F 1130, "Standard Practice for Inspecting the Coating System of a Ship." This is an extremely thorough practice, which requires the skills of a well-trained, experienced marine coatings inspector. The inspection technique divides the ballast tank into seven sections-forward bulkhead, aft bulkhead, inboard bulkhead, outboard bulkhead, top, bottom, and stiffeners. The practice allows for grading of the type of failure, extent of failure, and the distribution of the failure. The degree of rust is reported per ASTM D 610.

**Metal Thickness Measurements (Ultrasonic)**

As supplied steel is generally thicker than the specified minimum. For 0.25-inch thick plate, the actual thickness may range up to 0.28 inches thick. After five years of testing, a base line thickness was determined using ultrasonic thickness readings. The results of these measurements were reported in NSRP #0280, "Cathodic Protection/Partial Coatings verses Complete Coating in Ballast Tanks-Five Year report, November 1987. This data is reproduced below. Only plate thickness for each tank was reported at that time. Stiffener section thickness was not reported.

**Baseline Ultrasonic Steel Thickness Readings (Inches)**

| Tank 1 | Tank 2 | Tank 3 | Tank 4 | Tank 5 | Tank 6 |
|---|---|---|---|---|---|
| 0.270 | 0.270 | 0.270 | 0.245 | 0.255 | 0.270 |
| 0.265 | 0.270 | 0.270 | 0.260 | 0.245 | 0.270 |
| 0.250 | 0.270 | 0.255 | 0.250 | 0.245 | 0.270 |
| 0.245 | 0.270 | 0.270 | 0.255 | 0.245 | 0.270 |
| 0.250 | 0.270 | 0.245 | 0.255 | 0.250 | 0.270 |
| 0.255 | 0.265 | 0.250 | 0.250 | 0.245 | 0.275 |
| 0.265 | 0.265 | 0.245 | 0.260 | 0.255 | 0.270 |
| 0.265 | 0.270 | 0.250 | 0.265 | 0.245 | 0.270 |
| 0.258 | 0.268 | 0.257 | 0.255 | 0.248 | 0.271 (Average) |

The actual metal loss in each tank is a good measure of the system performance and is also an indication as to when structure must be replaced due to decreases in section and thus load carrying capacity. The regulator agencies such as the American Bureau of Shipping (ABS) have stringent rules governing metal replacement. When coating systems fail and are not replaced, significant metal loss can occur. Metal replacement in conjunction with coating system replacement results is large capital outlays.
Table 6 contains the measured metal thickness readings after twenty years.

## 4.2 Performance Results of Each System

**Epoxy "A" - Hand Cleaned Steel verses Sweep Cleaned Steel (SP-7)**

At end of the initial three years of testing, the hand tool cleaned tank performed somewhat better than the sweep blast cleaned tank. At the three year stage of the project, it would have been difficult to use the performance results of the hand tool cleaned tank lining system to support the use of power tool cleaning in lieu of abrasive blasting. This is especially true since, after five years of testing (two additional years), the performance of the two systems reversed and the hand tool cleaned tank was graded to be a Rust Grade 4, Failure – requiring replacement. The abrasive sweep blast cleaned (SSPC SP-7) tank was a Rust Grade 6. See Photographs 6 and 7.

Because the one system had failed, repairs were made to both systems, and the testing was reinitiated. The hand tool cleaned tank system was repaired using hand tool cleaning techniques. The sweep blast cleaned system was spot blasted to remove failed coatings and the balance of the surface was sweep blasted. After repair and re-exposure for an additional seven years, the sweep blast cleaned tank was superior. The hand tool tank was a Rust Grade 4.5, and the sweep blast cleaned tank was a Rust Grade 7.5. There was major edge breakdown on the top stiffener in the hand tool cleaned tank; however, overall, the Epoxy "A" coating system demonstrated relatively good edge protection.

From the ultrasonic thickness readings after twenty years, Tank One (Surface Tolerant Epoxy "A" over hand tool cleaned substrate) had very little metal loss on the flats except for one area on the tank bottom. There was major reduction in section on one back stiffener. Tank Four (Surface Tolerant Epoxy "A" over sweep blast cleaned substrate) had more overall metal loss; however, not significantly different from the baseline data from the 1987 report. The original system in Tank Four was the pre-construction primer with aluminum anode, which failed in three years. Subtracting the present thickness readings from the baseline data for each tank, Tank One has an overall average metal loss of 0.006 inches or 6 mils. Tank Four has an overall metal loss of 17 mils. If the stiffening metal loss is not considered for Tank Four, there is no measurable difference after twenty years. Remember that the baseline data in 1987 only included flats.

In summary, the sweep blast cleaned system provided good protection for twelve years with one maintenance cycle at five years to include reasonable edge protection. The power tool cleaned surface did not provide adequate protection.

**Epoxy "B" – Initial Commercial Blast Cleaning (SP-6) with Hand Tool Cleaned Repairs**

The Epoxy "B" coated tank has been under test for a total of fifteen years. See Photograph 8. Following the initial six years of testing, this system was beginning to show significant breakdown – Rust Grade 2. The top of the tank had twenty-five to fifty percent failures. The right side of the tank had totally failed. The balance of the tank had between five and ten percent failure.

The system was repaired using hand tool cleaning (SSPC-SP 2). After another two years of testing (eight years total), the overall failure was less than one percent with only minor breakdown on the edges of the overhead stiffener. No failure was observed on the balance of the structure. The coating system was again spot repaired at this time using hand tool cleaning.

After seven additional years of testing (fifteen totals), the top overhead and top back stiffener have major edge breakdown. The right side, lower left quadrant has also failed. This is an interesting observation in that no matter which coating system has been applied to this tank, this exact location fails during each test project. The reason for this unique failure is not known but it is believed that microbiological influenced corrosion (MIC) may be the cause.

This Tank is Tank Five on the Ultrasonic Thickness Tables. After twenty years there is no significant metal loss except on the bottom frame and top stiffener.

As with the Surface Tolerant Epoxy "A", the system provides approximately six years of protection before requiring repair and replacement of failed coatings.

### VOC Compliant Version of Mil-P-24441

As with the two Surface Tolerant Epoxy Systems, the Mil-P-24441 system was initially applied over a salt contaminated, substandard surface preparation. An attempt was made to achieve a Near White Blast Cleaning (SP-10); however, the surface flash rusted due to salt contamination on the surface prior to the application of the coating system. The system was applied over the flash rust. After five years of testing, failed areas were repaired using hand tool cleaning techniques.

At the end of the first five years of testing, the Mil-P-24441 was still providing adequate protection except for failure of the sharp edges of stiffeners, especially the top stiffener, which had major reduction in selection due to exfoliation. Again at the conclusion of twelve year, the system is providing good protection to the flats but has totally failed on the sharp edges. This corresponds with the service experience of the US Navy, which has lead to a program of developing edge retention lining systems. See Photograph 9.

This system was applied to Tank Seven. As with the Surface Tolerant Epoxy systems, no significant metal loss was recorded except for the top stiffener, which had a loss of 0.125 (one-half of section thickness) inches at the edge forming a knife-edge. The metal loss was limited to the edge.

The Mil-P-24441 performed well as surface tolerant epoxy systems. This was also noted in NSRP 0451, "Evaluation of Coatings applied on Less Than Ideal Surfaces, " published in September 1995. As with the two commercial surface tolerant epoxy coating systems, the Mil-P-24441 system can provide long term corrosion protection with intermediate repairs being made at five to seven years intervals. Either spot blasting sweep blasting, or hand tool cleaning techniques may be used depending on the severity of the failure or the time allotted for repairs. The U.S. Navy grading technique, which uses the Carrier Life Enhancing Repair (CLER) Aircraft Carrier Tank and Void Inspection Booklet is a good tool for performing the inspections and scheduling maintenance. The danger in this approach is that maintenance will be delayed due to operational or financial considerations. Special care must be exercised when evaluating edge failures, which in turn influence the load carrying capacity of the member. This then becomes the major driving factor in scheduling coating system repair and maintenance.

### Aged Coating System with Added Zinc Anode

Very little change was noted in the performance of the aged epoxy (Mil-P-23236) over the life of the system, once the zinc anode was added. This has proven to be a true twenty-year system. No new coating failure was detected in the fourteen years since the anode was added. Calcareous deposits continue to increase. Very little anode consumption was noted. See Photograph 10.

This system was installed in Tank Two. The overall metal loss in Tank two was 23 mils in twenty years. Most of the loss was in the tank bottom frame, which had an average metal loss of half the thickness; the top stiffener, and the right side, which is the common side with the partially coated tank. This will be discussed in the next section.

### Zinc Anode with Partial Coatings

After twenty years of testing, partial coating with zinc anode is still providing protection to the coated portion of the steel substrate. The zinc anode (50-pound) was replaced after twelve years with a new Thermal Reduction Company TRC-TZ-50-WC zinc anode (50 pounds). The color of the bare portion of the tank is the color of the calcareous deposit with possibly some red color being picked up due to the system failure.

As stated above this system was applied in Tank Three, which is adjacent to the aged coating with added zinc anode. When evaluated as to where the metal loss actually occurred, the bare areas in this partially coated tank loss approximately 100 mils, or almost half the thickness in twenty years. The stiffener thickness loss ranged from 1/8 inch on the back top stiffener to 1/16 inch on the other stiffeners.

This system requires further evaluation prior to selection as a corrosion control alternative. It could be that the calcareous deposits initially form during the ballasted condition and provides adequate protection. As the deposit increases in thickness, there is a tendency for the deposit to dry out during the de-ballasted or dry portion of the cycle, partially detaching from the substrate, forming a void between the calcareous deposit and the steel substrate. The partially detached deposit can shield the cathodic protection from further protection of the underlying substrate. Once the deposit completely detaches and falls off the surface, new deposits form providing protection until the thickness increases. One solution may be periodic removal of all loose deposits during dry-docking and maintenance. This would be much less expensive than re-coating the tank. The loss of half the metal thickness appears severe until it is remembered that the system performed for twenty years with no maintenance except anode replacement. It should also be remembered that cathodic protection only provides protection during the wet portion of the cycle – twenty days of the thirty-day cycle. See Photograph 11.

### VOC Compliant Alkyl Silicate Inorganic Zinc With and Without Cathodic Protection

At the conclusion of seven years of testing, both the inorganic zinc with and without zinc anode are providing good protection, with the system with the zinc anode demonstrating superior performance with less than 0.03% failure. The system without the zinc anode is showing some edge failure at seven years; whereas, the system with the anode has no edge failure. Very little anode consumption was noted. Based on the earlier results, where the thin film pre-construction zinc primer went ten years prior to failure, the full thickness inorganic zinc coating with zinc anode should provide twenty years of protection, thus being a permanent system for the life of the ship. See Photographs 12, and 13.

Both Tank Six (Inorganic Zinc with Zinc Anode) and Tank Nine (Inorganic Zinc only) show no metal loss during seven years of testing.

### Waterborne Zinc over Blast Cleaned Steel

The high ratio inorganic zinc coating failed after eight years of testing. No zinc anode was used with this system. Major edge failure was noted to include extreme exfoliation. The balance of the flat area range from rust grade 9 to 4. At the end of seven years, which is comparable to the solvent based inorganic zinc coating system discussed above, this system was an overall Rust Grade 6.5; whereas, the solvent based system without zinc anode was a Rust Grade 7.4. See Photograph 14.

This is Tank Eight in Table 6. No significant metal loss occurred on the flats; however, the bottom frame had metal penetration after ten years of testing. There was also major reduction in section on one of the back stiffeners.

High ratio, waterborne inorganic zinc systems are known to be sensitive to surface contamination. This test further demonstrates this sensitivity. Waterborne inorganic zinc coating systems should only be applied over clean substrates with all salt and other contamination removed. If the test could be repeated, a good control would have been high pressure water cleaned after initial abrasive blast cleaning followed by re-blasting to Near White Blast Clean (SP-10) followed by the application of the waterborne inorganic zinc.

### Anode Performance

As stated earlier in this report, the original anode system life was calculated as four years using standard cathodic protection design calculation methods. A twenty-pound aluminum (Galvalum III) anode and a fifty-pound zinc (Mil-A-18001H) were calculated to meet this requirement. The aluminum anode actually provided six years of performance, which equates to a fifty-percent increase in actual life over calculated life. The zinc anode provided protection for thirteen years, or three times the design life. In the re-test of the full thickness inorganic zinc coating with zinc anode, the anode weight was reduced to a standard twelve-pound anode. At the end of seven years, very little anode consumption was noted. Assuming that the inorganic zinc coated area represents a totally coated surface, the twelve-pound anode should theoretically last for a minimum of twelve years before replacement. This would then equate to one anode replacement cycle in twenty years.

## 3. PROJECT BENEFITS

Four direct benefits can be realized from the results of this project. These include:

1. Verification that the use of surface-tolerant epoxy systems for either touch-up and repair of existing systems or as total replacement systems applied over what has previously been considered substandard surface preparation, i.e., hand or power tool cleaning, has the potential to significantly reduce the cost of maintaining ship's ballast tanks.

2. Verification that the surface tolerant epoxy and Mil-P-24441 epoxy coating systems have a system life of approximately six years, but that with maintenance, these systems can provide long term corrosion protection.

3. Verification that zinc anodes, or other cathodic protection, can be added to partially failed, existing coating systems in lieu of coating repair or replacement. The cost of zinc anode

installation should be significantly less than coating replacement. Also, the generation of toxic and hazardous waste from tank coating operations would be eliminated.

4. Verification that full thickness inorganic zinc with cathodic protection can significantly extend the repair or replacement cycle for ballast tank coating systems.

5. Verification that total removal of an existing coating system is not necessary when performing maintenance and repair of ballast tank coating systems.

Edge failure of organic, high performance epoxy coating systems necessitates special consideration. Inorganic zinc coating systems with CP offer one low cost solution. High performance, epoxy-coating systems with CP offer another solution. Edge retention, high solids coating systems hold promise, but are yet unproven in long term exposure tests.

| Table 3 | |
|---|---|
| TANK No. ONE | COATING SYSTEM: SURFACE TOLERANT EPOXY "A" VOC COMPLIANT (AMERON 385P/385). (SYSTEM LIFE-7 YEARS) COATING APPLIED TO OVERHEAD IS ORGINAL COATING SYSTEM – 20 YEARS OLD. SURFACE PREPARATION: SP-2/SP-3; PREVIOUS SYSTEM: SAME |
| TOP-FLAT<br>DFT-N/A | RUST GRADE 6<br>CLER CONDITION # 2 |
| TOP-STIFFENER<br>DFT-N/A | COMPLETE EDGE BREAKDOWN; MAJOR REDUCTION IN SECTION<br>CLER CONDITION # 4 |
| BACK-FLAT<br>DFT-14.5 MILS | RUST GRADE 4<br>CLER CONDITION # 4 |
| BACK-TOP STIFFENER<br>DFT-9.8 MILS | RUST GRADE 2<br>CLER CONDITION # 4<br>MAJOR REDUCTION IN SECTION |
| BACK-BOTTOM STIFFENER<br>DFT-26 MILS | RUST GRADE 2<br>CLER CONDITION # 4<br>MAJOR REDUCTION IN SECTION |
| BOTTOM-FLAT<br>DFT-22.7MILS | RUST GRADE 6. FRONT RIGHT QUADRANT CRACKING AT WELD. RUST AT DRAIN OPENING RIGHT FRONT.<br>CLER CONDITION # 2 |
| BOTTOM-STIFFENER<br>DFT-19 MILS | RUST GRADE 6. EDGE BEGINNING TO FAIL.<br>CLER CONDITION # 3 |
| BOTTOM-FRAME<br>DFT-16.2MILS | RUST GRADE 4<br>CLER CONDITION # 4 |
| RIGHT SIDE<br>DFT-13.3 MILS | RUST GRADE 4<br>CLER CONDITION # 4 |
| LEFT SIDE<br>DFT-15 MILS | RUST GRADE 6<br>CLER CONDITION # 2 |
| LID | RUST GRADE 8, CLER CONDITION 1 |

Table 3 (continued)

| TANK No. TWO | COATING SYSTEM: MIL-P-23236 COATING WITH ZINC ANODE (SYSTEM LIFE-20 YEARS) ORIGINAL DRY FILM THICKNESS RECORDED AS 6.5 to 8.5 MILS.<br>SURFACE PREPARATION: SP-10<br>PREVIOUS SYSTEM: ANODE ADDED AFTER 6 YEARS OF TESTING. NOT REPLACED TO DATE. |
|---|---|
| TOP-FLAT | TOTAL FAILRE AROUND THE PERIPHERY, BALANCE RUST GRADE 6.<br>CLER CONDITION # 4 |
| TOP-STIFFENER | TOTAL EDGE FAILURE. 3/16 INCH THICKNESS REMAINING<br>CLER CONDITION # 4 |
| BACK-FLAT | RUST GRADE 6 WITH CALCAREOUS DEPOSITS AT COATING FAILURE S. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| BACK-TOP STIFFENER | RUST GRADE 6 WITH CALCAREOUS DEPOSITS AT COATING FAILURE S. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| BACK-BOTTOM STIFFENER | RUST GRADE 6 WITH CALCAREOUS DEPOSITS AT COATING FAILURE S. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| BOTTOM-FLAT | FAILED AND SCALEING. CLER CONDITION # 4 |
| BOTTOM-STIFFENER | FAILED AND SCALEING. 3/16 INCH THICKNESS REMAINING.<br>CLER CONDITION # 4 |
| BOTTOM-FRAME | FAILED AND SCALEING. 1/8 INCH THICKNESS REMAINING.<br>CLER CONDITION # 4 |
| RIGHT SIDE | RUST GRADE 6 WITH CALCAREOUS DEPOSITS AT COATING FAILURE S. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| LEFT SIDE | RUST GRADE 6 WITH CALCAREOUS DEPOSITS AT COATING FAILURE S. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| LID | RUST GRADE 8. CLER CONDITION # 2 |

**Table 3 (continued)**

| TANK No. THREE | COATING SYSTEM: MIL-P-23236 PARTIAL WITH ZINC ANODE (SYSTEM LIFE-20 YEARS). ORIGINAL DRY FILM THICKNESS FOR COATED AREAS RECORDED AS 6 TO 9.5 MILS. FLAT BOTTOM REPAIRED AND ANODE REPLACED AFTER 13 YEARS.<br>SURFACE PREPARATION: SSPC-SP-10 INITIAL/SP-2 REPAIR OF BOTTOM; PREVIOUS SYSTEM: MIL-P-23236 |
|---|---|
| TOP-FLAT | RUST GRADE 5 WITH CALCAREOUS DEPOSITS.<br>CLER CONDITION # 3 |
| TOP-STIFFENER | RUST GRADE 8. VERY LITTLE CHANGE THROUGH THE ENTIRE TESTING PERIOD. PRIMARILY RUST STAINS ONLY.<br>CLER CONDITION # 1 |
| BACK-FLAT | UNPAINTED AREA (HEAVY CALCAREOUS SCALE)-CLER CONDITION # 4. PAINTED AREAS (TOP AND BOTTOM)-VERY LITTLE CHANGE THROUGH THE ENTIRE TESTING PERIOD. RUST GRADE 8, PRIMARILY RUST STAINS ONLY.<br>CLER CONDITION # 1 |
| BACK-TOP STIFFENER | MAJOR FAILURE. MAJOR REDUCTION IN SECTION. 1/8 INCH THICKNESS REMAINING.<br>UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4 |
| BACK-BOTTOM STIFFENER | UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4 |
| BOTTOM-FLAT REPAIR 5 YEARS OLD | RUST GRADE 8<br>CLER CONDITION # 2 |
| BOTTOM-STIFFENER | MAJOR EDGE EXFOLIATION. 3/16 INCH THICKNESS REMAINING.<br>CLER CONDITION # 2 ON FLATS. |
| BOTTOM-FRAME | RUST GRADE 4. MAJOR EDGE EXFOLIATION. 3/16 INCH THICKNESS REMAINING.<br>CLER CONDITION # 4 |
| RIGHT SIDE | UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4. PAINTED AREAS (TOP AND BOTTOM) RUST GRADE 8. VERY LITTLE CHANGE THROUGH THE ENTIRE TESTING PERIOD. PRIMARILY RUST STAINS. CLER CONDITION # 1 |
| LEFT SIDE | UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4. PAINTED AREAS (TOP AND BOTTOM ) RUST GRADE 8. VERY LITTLE CHANGE THROUGH THE ENTIRE TESTING PERIOD. PRIMARILY RUST STAINS ONLY.CLER CONDITION # 2 |
| LID | RUST GRADE 10. CLER CONDITION # 2 |

Table 3 (continued)

| TANK No. FOUR | COATING SYSTEM: SURFACE TOLERANT EPOXY "A" VOC COMPLIANT (AMERON 385P/385) (SYSTEM LIFE-7 YEARS)<br>SURFACE PREPARATION: SP-7<br>PREVIOUS SYSTEM: SAME OVER SP-10 |
|---|---|
| TOP-FLAT<br>DFT-16.2 MILS | RUST GRADE 9 EXCEPT FOR FAILURES AROUND FILL PORT.<br>CLER CONDITION # 1 |
| TOP-STIFFENER<br>DFT-13.6 MILS | GOOD EDGE PROTECTION. NO EDGE BREAKDOWN. RUST GRADE 9 ON FLATS; 6 ON FLANGES. EDGE OF STIFFENER 1/8 INCH THICK TAPERING UP TO FULL THICKNESS.<br>CLER CONDITION # 1 |
| BACK-FLAT<br>DFT-15.8 MILS | RUST GRADE 9. SOME RUST STREAKS.<br>CLER CONDITION # 2 |
| BACK-TOP STIFFENER<br>DFT-18.2 MILS | RUST GRADE 6. 3/16 INCH THICKNESS REMAINING. TOP EDGE FAILING.<br>CLER CONDITION # 3 |
| BACK-BOTTOM STIFFENER<br>DFT-14.4 MILS | BETTER THAN TOP STIFNER. RUST GRADE 8. 3/16 INCH THICKNESS REMAINING.<br>CLER CONDITION # 2 |
| BOTTOM-FLAT<br>DFT-19.8 MILS | RUST GRADE 8<br>CLER CONDITION # 2 |
| BOTTOM-STIFFENER<br>DFT-17 MILS | RUST GRADE 6. MINOR EDGE BREAKDOWN. 3/16 INCH THICKNESS REMAINING.<br>CLER CONDITION # 2 |
| BOTTOM-FRAME<br>DFT-15 MILS | RUST GRADE 8. MINOR EDGE FAILURE. 1/16 INCH THICKNESS REMAINING ON FLANGE EDGE; 3/16 INCH THICKNESS REMAINING ON WEB. CLER CONDITION # 2 |
| RIGHT SIDE<br>DFT-13.1 MILS | RUST GRADE 8<br>CLER CONDITION # 1 |
| LEFT SIDE<br>DFT-14.9 MILS | BOTTOM FRONT QUADRANT RUSTGRADE 4 AND CLER CONDITION 3. BALANCE RUST GRADE 9<br>CLER CONDITION # 2 |
| LID | RUST GRADE 8, CLER CONDITION 1 |

Table 3 (continued)

| TANK No. FIVE | ORIGINAL COATING SYSTEM: SURFACE TOLERANT SYSTEM B (DEVOE 235)(SYSTEM AGE 15 YEARS)<br>ORIGINAL SURFACE PREPARATION: SP-6.<br>REPAIR SURFACE PREPARATION: SP-2 MINOR AREAS ONLY @ 6 AND 8 YEARS.<br>REPAIR SYSTEM: DEVOE 236 SMALL AREAS. (REPAIR SYSTEM AGES 6 and 8 YEARS) |
|---|---|
| TOP-FLAT<br>DFT-14.4 MILS | RUST GRADE 8.<br>CLER CONDITION # 2 |
| TOP-STIFFENER<br>DFT-15.3 MILS | RUST GRADE 6. MAJOR EDGE FAILURE. SOME METAL LOSS.<br>CLER CONDITION # 4 |
| BACK-FLAT<br>DFT-18 MILS | RUST GRADE 6.<br>CLER CONDITION # 2 |
| BACK-TOP<br>STIFFENER<br>DFT-21.8 MILS | TOP OF STIFFENER IS DELAMINATING AND LIFTING. BALANCE RUST GRADE 6.<br>NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4 |
| BACK-BOTTOM<br>STIFFENER<br>DFT-22.4 MILS | TOP OF STIFNER BEGINNING TO FAIL. RUST GRADE 8. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 2 |
| BOTTOM-FLAT<br>DFT-16.4 MILS | RUST GRADE 7<br>CLER CONDITION # 2 |
| BOTTOM-STIFFENER<br>DFT- | EDGES BEGINNING TO FAIL. RUST GRADE 6. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 3 |
| BOTTOM-FRAME<br>DFT-24.9 MILS | RUST GRADE 4. NO SIGNIFICANT METAL LOSS.<br>CLER CONDITION # 4. |
| RIGHT SIDE<br>DFT-16.7 MILS | RUST GRADE 4. LOWER LEFT QUADRANT FAILED. THIS SAME AREA HAS FAILED EACH TIME A NEW COATING SYSTEM HAS BEEN APPLIED.<br>CLER CONDITION # 4 |
| LEFT SIDE<br>DFT-12.3 MILS | RUST GRADE 6 EXCEPT AROUND ATTACHMENT OF STIFNER TO SIDEWALL AT BOTTOM, RUST GRADE 2, and CLER 4. BALANCE CLER CONDITION # 3. |
| LID | RUST GRADE 6, CLER CONDITION 2 |

| Table 3 (continued) | |
|---|---|
| TANK No.<br>SIX | COATING SYSTEM: VOC COMPLIANT INORGANIC ZINC W/ZINC ANODE (CARBO ZINC 11HS) (SYSTEM LIFE-7 YEARS)<br>SURFACE PREPARATION: SP-10 (AGED PRECONSTRUCTION COMPLETELY REMOVED)<br>PREVIOUS SYSTEM: PRECONSTRUCTION ZINC PRIMER W/ZINC ANODE (SIGMA) |
| TOP-FLAT<br>DFT-13 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS. SOME OF THE DEPOSITS ARE FLAKING OFF WITH ZINC VISIBLE UNDER THE FLAKED AREA. NO RUST.<br>CLER CONDITION # 1 |
| TOP-STIFFENER<br>DFT-9.5 MILS | RUST GRADE 9 WITH CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BACK-FLAT<br>DFT-13.3 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BACK-TOP STIFFENER<br>DFT-12.3 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BACK-BOTTOM STIFFENER<br>DFT-11.7 MILS | RUST GRADE 8 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BOTTOM-FLAT<br>DFT-9.5 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BOTTOM-STIFFENER<br>DFT-10.2 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BOTTOM-FRAME<br>DFT-7.6 MILS | RUST GRADE 8 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1; SOME EDGE FAILURE |
| RIGHT SIDE<br>DFT-9.7 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| LEFT SIDE<br>DFT- | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| LID | RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. |

NOTE: VERY LITTLE ANODE DEMAND.

Table 3 (continued)

| TANK No. SEVEN | COATING SYSTEM: VOC COMPLIANT MIL-P-24441 REPAIRED W/MIL-P-24441 (AMERON ORIGINALLY; REPAIRED WITH DEVOE) (SYSTEM LIFE-ORIGINAL SYSTEM REPAIRED AFTER 5 YEARS. REPAIR AREAS 7YEARS. TOTAL 12 YEARS)<br>SURFACE PREPARATION: SP-2/3<br>PREVIOUS SYSTEM: SAME W/SP-10 SURFACE PREPARATION |
|---|---|
| TOP-FLAT<br>DFT-7.7 MILS | RUST GRADE 8 EXCEPT FOR FAILURE AROUND FILL PORT.<br>CLER CONDITION # 1 |
| TOP-STIFFENER<br>DFT-11.8 MILS | SEVERE BREAKDOWN ON FRONT AND BACK EDGE. RIGHT SIDE RUST GRADE 8, BALANCE.<br>CLER CONDITION # 4 |
| BACK-FLAT<br>DFT-12.9 MILS | TOP AND CENTER-RUST GRADE 10. BOTTOM RIGHT-RUST GRADE 6. RUST GRADE 10 BALANCE OF BOTTOM. CLER CONDITION # 2 |
| BACK-TOP STIFFENER<br>DFT-14.6 MILS | RUST GRADE 8<br>CLER CONDITION # 2 |
| BACK-BOTTOM STIFFENER<br>DFT-17.3 MILS | RUST GRADE 8<br>CLER CONDITION # 2 |
| BOTTOM-FLAT<br>DFT-16.6 MILS | RUST GRADE 8<br>CLER CONDITION # 2 |
| BOTTOM-STIFFENER<br>DFT-13.6 MILS | RUST GRADE 6 WITH EDGE BREAKDOWN.<br>CLER CONDITION # 2 |
| BOTTOM-FRAME<br>DFT-15 MILS | RUST GRADE 4<br>CLER CONDITION # 4 |
| RIGHT SIDE<br>DFT-15.8 MILS | RUST GRADE 8<br>CLER CONDITION # 1 |
| LEFT SIDE<br>DFT-14.9 MILS | RUST GRADE 9<br>CLER CONDITION # 1 |
| LID | RUST GRADE 8, CLER 2. |

**Table 3 (continued)**

| TANK No. EIGHT | COATING SYSTEM: WATERBORNE HIGH RATIO INORGANIC ZINC (INORGANIC COATINGS)<br>SURFACE PREPARATION: SP-10<br>PREVIOUS SYSTEM: SAME. (SYSTEM LIFE 9 YEARS) |
|---|---|
| TOP-FLAT<br>DFT-7.2 MILS | RUST GRADE 9<br>CLER CONDITION # 1 |
| TOP-STIFFENER<br>DFT- | EDGE BREAKDOWN WITH EXFOLIATION. LEFT HALF FAILED. RIGHT HALF AND BACK SIDE RUST GRADE 4. CLER CONDITION # 4 |
| BACK-FLAT<br>DFT-7.8 MILS | TOP AND CENTER RUST GRADE 7 WITH RUST STREAKING. BOTTOM SECTION RUST GRADE 4, CLER CONDITION 4. BALANCE CLER CONDITION # 3 |
| BACK-TOP STIFFENER<br>DFT- | TOP FAILED. RUST STREAKING. STEEL DELAMINATION/EXFOLIATION FROM RUST UNDER INORGANIC ZINC COATING.<br>CLER CONDITION # 4 |
| BACK-BOTTOM STIFFENER<br>DFT- | EDGE FAILURE. BALANCE RUST GRADE 4.<br>CLER CONDITION # 4 |
| BOTTOM-FLAT<br>DFT-9.4 MILS | RUST GRADE 4<br>CLER CONDITION # 4 |
| BOTTOM-STIFFENER<br>DFT- | RIGHT SIDE FAILED WITH PENTRATION OF THE MEMBER. LEFT SIDE FAILED; RUST GRADE 2 ON RIGHT SIDE. CLER CONDITION # 4 |
| BOTTOM-FRAME<br>DFT- | TOTAL FAILURE WITH PENETRATION OF THE MEMBER.<br>CLER CONDITION # 4 |
| RIGHT SIDE<br>DFT-5.6 MILS | BOTTOM FRONT AND REAR FAILED 6 INCHES UP FROM BOTTOM RUST GRADE 4. BALANCE RUST GRADE 8.<br>CLER CONDITION # 3 |
| LEFT SIDE<br>DFT-7.4 MILS | RUST GRADE 8 EXCEPT FOR ONE AREA 6 INCHES BY 6 INCHES IN BOTTOM GUADRANT.<br>CLER CONDITION # 2 |
| LID | RUST GRADE 10, CLEAR CONDITION 1. |

Table 3 (continued)

| TANK No. NINE | COATING SYSTEM: VOC COMPLIANT INORGANIC ZINC (NO ANODES)(CARBO ZINC 11HS) (SYSTEM LIFE-7 YEARS)<br>SURFACE PREPARATION: SP-10<br>PREVIOUS SYSTEM: SURFACE TOLERANT SYSTEM B |
|---|---|
| TOP-FLAT<br>DFT-13.9 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| TOP-STIFFENER<br>DFT-9.1 MILS | RUST GRADE 6 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. MAJOR EDGE FAILURE.<br>CLER CONDITION # 3 |
| BACK-FLAT<br>DFT-9.2 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BACK-TOP STIFFENER<br>DFT-11.9 MILS | BOTTOM EDGE FAILURE WITH BALANCE RUST GRADE 8 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 2 |
| BACK-BOTTOM STIFFENER<br>DFT-7.3 MILS | BOTTOM EDGE FAILURE WITH BALANCE RUST GRADE 8 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 2 |
| BOTTOM-FLAT<br>DFT-11.7 MILS | RUST GRADE 8 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| BOTTOM-STIFFENER<br>DFT-8.5 MILS | AREA APPROXIMATELY 6 INCHES BY 4 INCHES ON RIGHT SIDE DELAMINATED AND DETACHED WITH BLACK DEPOSIT UNDER DETACHED AREA. NO SIGNIFICANT METAL LOSS.<br>BALANCE RUST GRADE 7. CLER CONDITION # 3 |
| BOTTOM-FRAME<br>DFT-8.5 MILS | FRONT SIDES - RUST GRADE 4. BACKSIDES – RUST GRADE 6 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. TOP OF FRAME RUSTGRADE 6.<br>CLER CONDITION # 4 |
| RIGHT SIDE<br>DFT-8.2 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| LEFT SIDE<br>DFT-8.4 MILS | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES.<br>CLER CONDITION # 1 |
| LID | RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION 1. |

Table 4
TWENTY YEAR PERFORMANCE SUMMARY - ASTM D610 (Overall Average Rating)

| SYSTEM | Surface Prep. | 1 Year | 2 Years | 3 Years | 4 Years | 5 Years | 6 Years | 7 Years | 8 Years | 9 Years | 10 Years | 11 Years | 12 Years | 13 Years | 14 Years | 15 Years | 20 Years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Partially Coated Mil-P-23236 w/Al Anode | SP10 | 9 | 9 | 8 | 6 | 6 | 4 | | | | | | | | | | |
| Mil-P-23236 | SP10 | 8 | 8 | 6 | 6 | 6 | 6 | 6 | 6 | | | | | | | | |
| Mil-P-23236 w/Zinc Anode | SP10 | | | | | | | | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4.7 |
| Partially Coated Mil-P-23236 w/Zinc Anode | SP10 | 10 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 6.8 |
| PCP w/Al Anode | SP10 | 6 | 6 | 4 | 2 | 2 | 2 | 2 | 2 | | | | | | | | |
| PCP | SP10 | 2 | 2 | 2 | 2 | | | | | | | | | | | | |
| PCP w/Zinc Anode | SP10 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 8 | 6 | 4 | | | | | |
| Soft Coating No. 1 w/Al Anode | Rust | F | | | | | | | | | | | | | | | |
| Soft Coating No. 1 | Rust | 9 | | | | | | | | | | | | | | | |
| Soft Coating No. 1 w/Zinc Anode | Rust | F | | | | | | | | | | | | | | | |
| Soft Coating No. 2 | Rust | F | | | | | | | | | | | | | | | |
| Surface Tolerant Epoxy "A" | SP2/SP3 | 9 | 7 | 7 | 5 | 4 | 8.7* | 8.5 | 8.2 | 7.6 | 7 | 5 | 4.5 | | | | |
| Surface Tolerant Epoxy "A" | SP7 | 8 | 6 | 6 | 5 | 6 | 9.5* | 9.4 | 9.1 | 8.5 | 8.5 | 7.8 | 7.5 | | | | |
| Surface Tolerant Epoxy "B" | SP6 | 9 | 9 | 8 | 7 | 7 | 7 | 7 | 7* | 8.8 | 8.5 | 8.4 | 6.5 | 6.5 | 5.7 | 5.5 | |
| Surface Tolerant Epoxy "B" | SP2/SP3 | F | | | | | | | | | | | | | | | |
| Mil-C-24441, Type IV | SP10 | 8 | | 7 | 7 | 7* | 8.9 | 8.5 | 8.1 | 7 | 7 | 7 | 7 | | | | |
| Inorganic Zinc w/Zinc Anode | SP10 | 10 | 10 | 10 | 9 | 9 | 9 | 9 | | | | | | | | | |
| Inorganic Zinc | SP10 | 9.8 | 9.6 | 9.5 | 8.1 | 8.3 | 8.1 | 7.4 | | | | | | | | | |
| WB High Ratio Inorganic Zinc | SP10 | 8 | 8 | 8 | 7.6 | 6.8 | 6.2 | 6.5 | 5.4 | 4.8 | 4 | | | | | | |

* System Repaired; this represents 1st Year Test Results

*Note: ASTM D610 Rust Grade 4 is generally considered as total failure, which requires repairs or replacement.*

| TABLE 5-COMPARISON OF CLER INSPECTION RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TANK No. | Top | Sides | Bottom | "T" Bars | Total | Top | Sides | Bottom | "T" Bars | Total |
| **Observer-Wheeler** | | | | | | **Observer-McCullom** | | | | |
| One | 2 | 2 | 1 | 2 | 7 | 1 | 1 | 1 | 2 | 5 |
| Two | 2 | 3 | 4 | 3 | 12 | 2 | 2 | 3 | 3 | 10 |
| Three | 2 | 4 | 1 | 4 | 11 | 2 | 4 | 2 | 4 | 12 |
| Four | 1 | 1 | 1 | 2 | 5 | 1 | 2 | 1 | 2 | 6 |
| Five | 1 | 2 | 1 | 2 | 6 | 1 | 1 | 1 | 1 | 4 |
| Six | 1 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 4 |
| Seven | 1 | 1 | 1 | 2 | 5 | 1 | 1 | 1 | 1 | 4 |
| Eight | 1 | 1 | 2 | 3 | 7 | 1 | 1 | 1 | 2 | 5 |
| Nine | 1 | 1 | 1 | 2 | 5 | 1 | 1 | 1 | 1 | 4 |
| **Observer-Demmon** | | | | | | **Observer-Fultz** | | | | |
| One | 1 | 2 | 1 | 2 | 6 | 2 | 2 | 2 | 2 | 8 |
| Two | 3 | 2 | 4 | 4 | 13 | 4 | 4 | 4 | 4 | 16 |
| Three | 2 | 4 | 3 | 4 | 13 | 2 | 1 | 1 | 4 | 8 |
| Four | 2 | 2 | 1 | 2 | 7 | 1 | 2 | 1 | 2 | 6 |
| Five | 1 | 2 | 1 | 3 | 7 | 1 | 2 | 1 | 3 | 7 |
| Six | 1 | 1 | 1 | 3 | 6 | 1 | 1 | 1 | 1 | 4 |
| Seven | 1 | 2 | 2 | 2 | 7 | 1 | 1 | 1 | 2 | 5 |
| Eight | 1 | 2 | 3 | 4 | 10 | 1 | 2 | 3 | 4 | 10 |
| Nine | 1 | 1 | 1 | 2 | 5 | 1 | 1 | 1 | 2 | 5 |

**Table 6 Metal Thickness Measurements (Ultrasonic) after Twenty Years**

| | Tank Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Location** | **One** | **Two** | **Three** | **Four** | **Five** | **Six** | **Seven** | **Eight** | **Nine** |
| Top Front Left | 0.271 | 0.289 | 0.279 | 0.156 | 0.232 | 0.257 | 0.273 | 0.278 | 0.278 |
| Top Front Right | 0.274 | 0.289 | 0.285 | 0.22 | 0.269 | 0.209 | 0.275 | 0.274 | 0.275 |
| Top Back Left | 0.274 | 0.279 | 0.28 | 0.2 | 0.25 | 0.246 | 0.277 | 0.275 | 0.28 |
| Top Back Right | 0.278 | 0.285 | 0.279 | 0.215 | 0.244 | 0.276 | 0.276 | 0.276 | 0.28 |
| Top Stiffener | MRS | 0.18 | 0.463 | 0.169 | NM | 0.38 | MRS | 0.24 | 0.346 |
| **Average Top** | **0.274** | **0.264** | **0.317** | **0.192** | **0.249** | **0.274** | **0.275** | **0.269** | **0.292** |
| Bottom Front Left | 0.146 | NM | 0.286 | 0.313 | 0.272 | 0.253 | 0.275 | 0.236 | 0.233 |
| Bottom Front Right | 0.316 | 0.29 | 0.282 | 0.294 | 0.292 | 0.235 | 0.275 | 0.231 | 0.217 |
| Bottom Back Left | 0.328 | NM | 0.316 | 0.299 | 0.291 | 0.262 | 0.278 | 0.24 | 0.258 |
| Bottom Back Right | 0.142 | NM | 0.284 | 0.292 | 0.298 | 0.24 | 0.278 | 0.225 | 0.265 |
| Bottom Stiffener | 0.348 | 0.18 | 0.18 | 0.18 | 0.301 | 0.33 | 0.275 | Penetrated | 0.389 |
| Bottom Frame | 0.306 | 0.12 | 0.18 | 0.24 | 0.158 | NM | 0.283 | Penetrated | 0.239 |
| **Average Bottom** | **0.264** | **0.197** | **0.255** | **0.270** | **0.269** | **0.264** | **0.277** | **0.233** | **0.267** |
| Back Top Left | 0.265 | 0.263 | 0.271 | 0.265 | 0.241 | 0.242 | 0.278 | 0.236 | 0.276 |
| Back Top Right | 0.265 | 0.267 | 0.167 | 0.23 | 0.242 | 0.266 | 0.265 | 0.245 | 0.274 |
| Back Bottom Left | 0.241 | 0.264 | 0.16 | 0.237 | 0.238 | 0.249 | 0.269 | 0.25 | 0.276 |
| Back Bottom Right | 0.242 | 0.267 | 0.157 | 0.25 | 0.239 | 0.264 | 0.263 | 0.26 | 0.274 |
| Back Top Stiffener | 0.145 | 0.292 | 0.12 | 0.184 | 0.255 | 0.286 | 0.278 | NM | 0.19 |
| Back Bottom Stiffener | 0.095 | 0.266 | 0.195 | 0.18 | 0.275 | 0.264 | 0.278 | 0.157 | 0.217 |
| **Average Back** | **0.209** | **0.270** | **0.178** | **0.224** | **0.248** | **0.262** | **0.272** | **0.230** | **0.251** |
| Left Side Top Front | 0.269 | 0.286 | 0.148 | 0.23 | 0.222 | 0.22 | 0.257 | 0.26 | 0.29 |
| Left Side Top Back | 0.239 | 0.293 | 0.184 | 0.294 | 0.243 | 0.283 | 0.259 | 0.253 | 0.255 |
| Left Side Bottom Front | 0.237 | 0.269 | 0.162 | 0.234 | 0.245 | 0.297 | 0.269 | 0.262 | 0.297 |
| Left Side Bottom Back | 0.227 | 0.307 | 0.16 | 0.299 | 0.266 | 0.289 | 0.266 | 0.277 | 0.262 |
| **Average Left Side** | **0.243** | **0.289** | **0.164** | **0.264** | **0.244** | **0.272** | **0.263** | **0.263** | **0.276** |
| Right Side Top Front | 0.286 | 0.148 | 0.272 | 0.222 | 0.22 | 0.266 | 0.26 | 0.29 | 0.266 |
| Right Side Top Back | 0.293 | 0.184 | 0.298 | 0.243 | 0.283 | 0.27 | 0.253 | 0.255 | 0.267 |
| Right Side Bottom Front | 0.269 | 0.162 | 0.14 | 0.245 | 0.297 | 0.269 | 0.262 | 0.297 | 0.265 |
| Right Side Bottom Back | 0.307 | 0.16 | 0.268 | 0.266 | 0.289 | 0.278 | 0.277 | 0.262 | 0.266 |
| **Average Right Side** | **0.289** | **0.164** | **0.245** | **0.244** | **0.272** | **0.271** | **0.263** | **0.276** | **0.266** |
| **Tank Average** | **0.252** | **0.245** | **0.232** | **0.238** | **0.256** | **0.268** | **0.271** | **0.253** | **0.270** |

Notes: NM - Not Measured; Could Not Be Measured
MRS - Major Reduction in Section

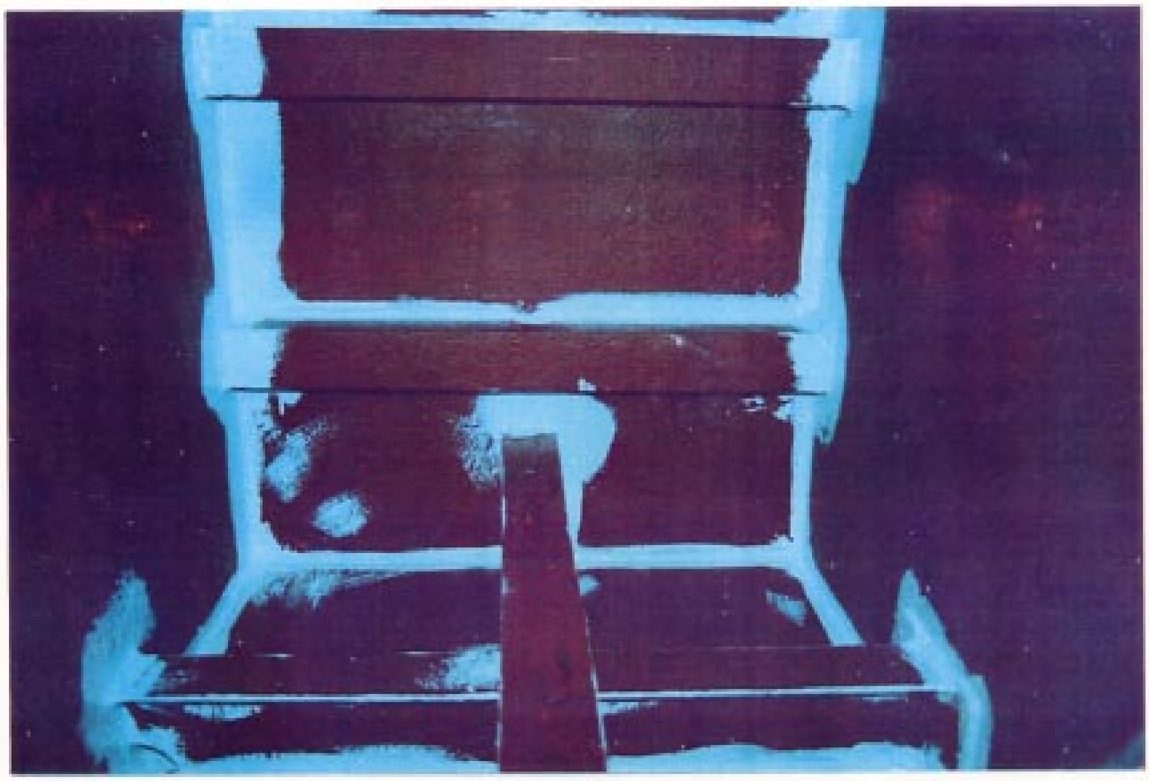
**PHOTOGRAPH 1-TEST TANK ASSEMBLIES**

PHOTOGRAPH 2A- SWEEP BLAST CLEANED SURFACE

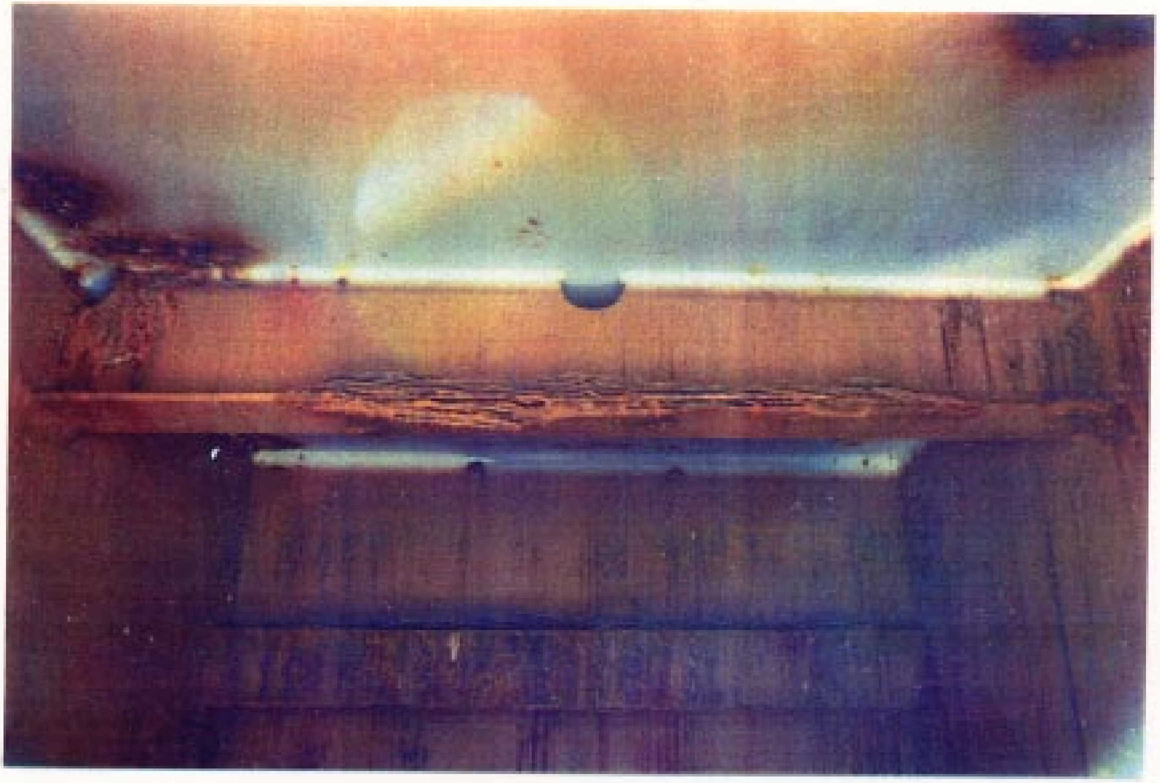
PHOTOGRAPH 2B- POWER & HAND TOOL CLEANED SURFACE

PHOTOGRAPH 3- REPAIR SURFACE PREPARATION TO MIL-P-24441

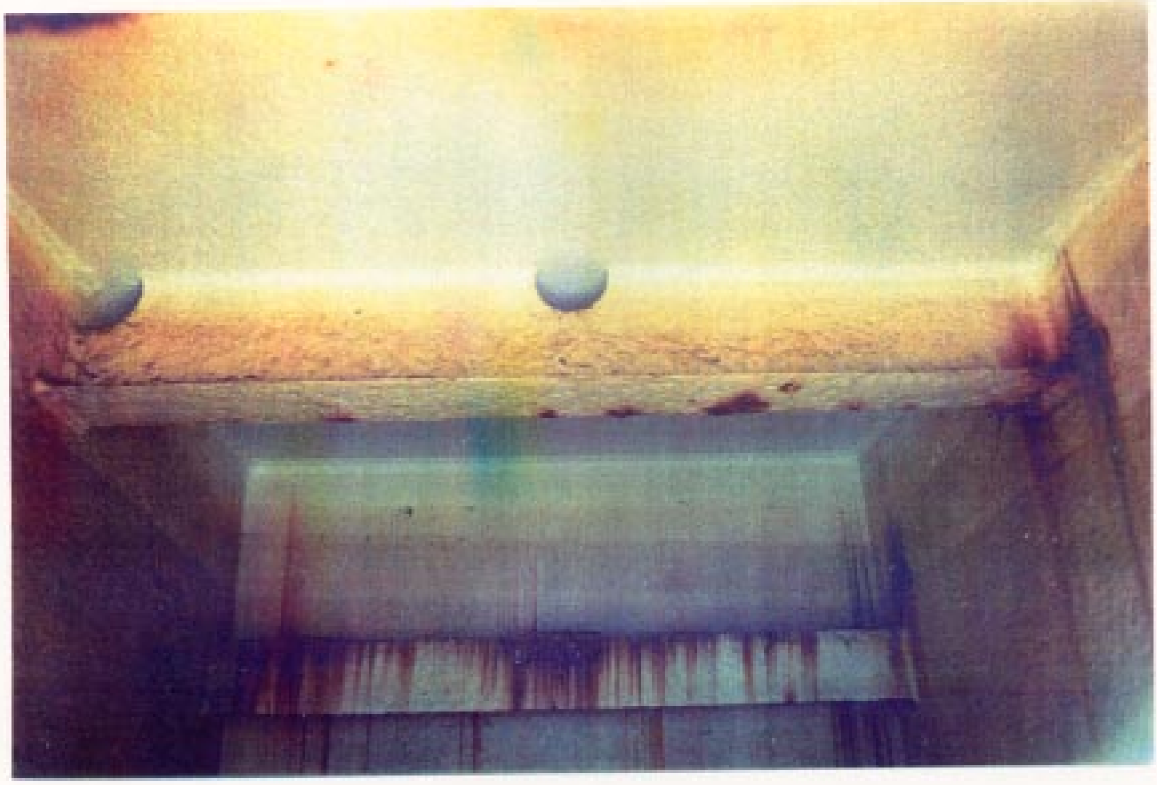
PHOTOGRAPH 4- NEAR WHITE CLEANED SURFACE SHOWING FLASH RUST

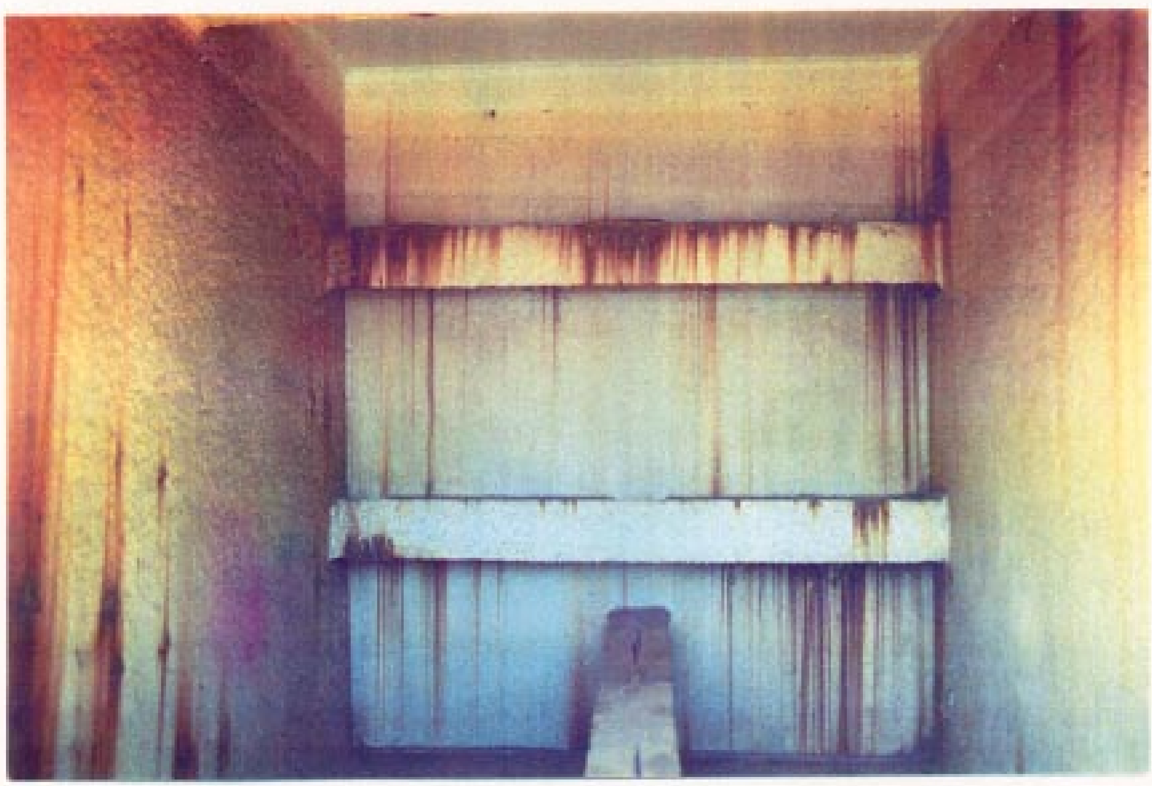


PHOTGRAPH 5- STRIPE COATING BETWEEN COATS



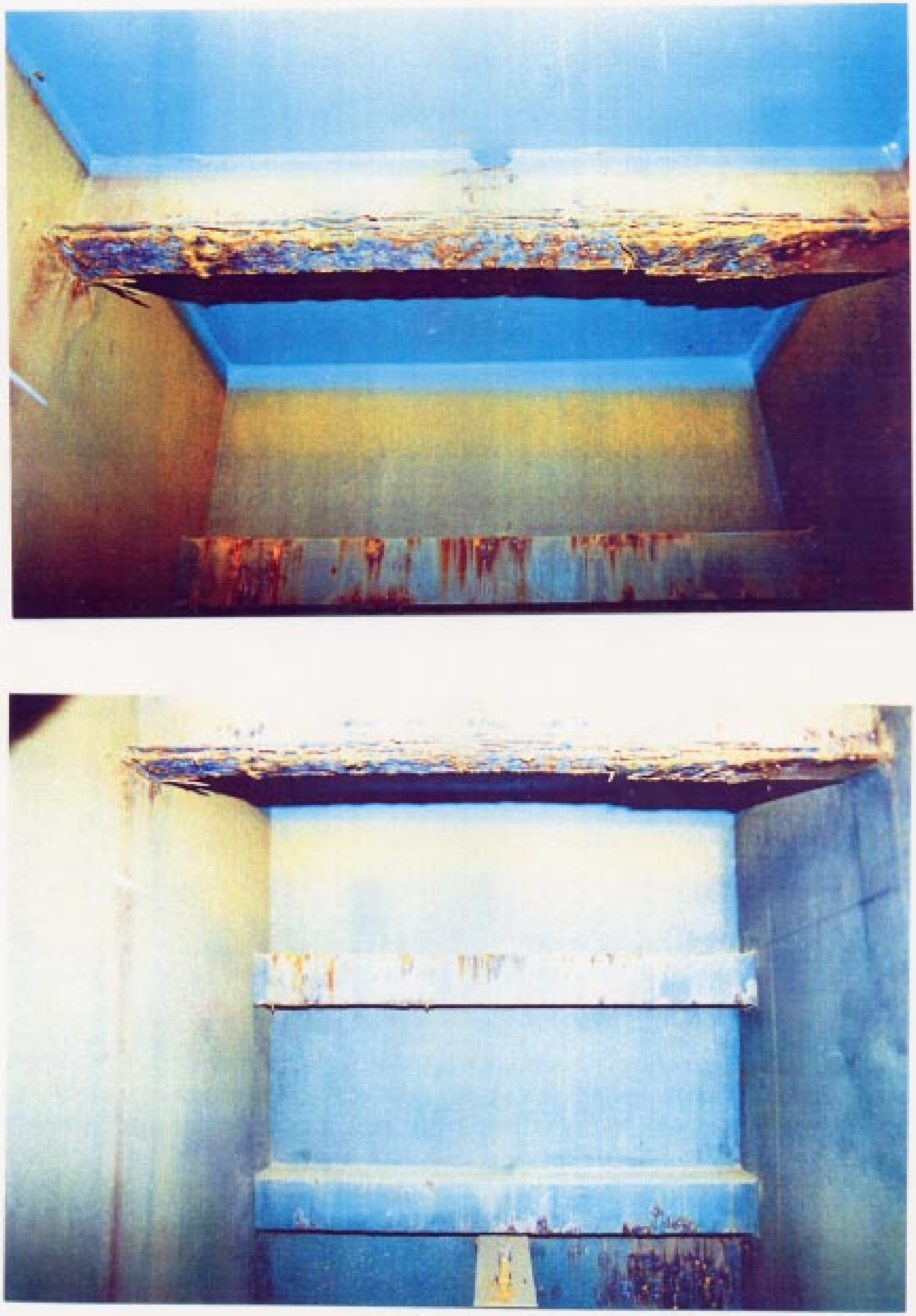
PHOTOGRAPH 6-SURFACE TOLERANT EPOXY A OVER HAND TOOL CLEANED SURFACE





**PHOTOGRAPH 7-SURFACE TOLERANT EPOXY A OVER SWEEP BLAST CLEANED SURFACE**

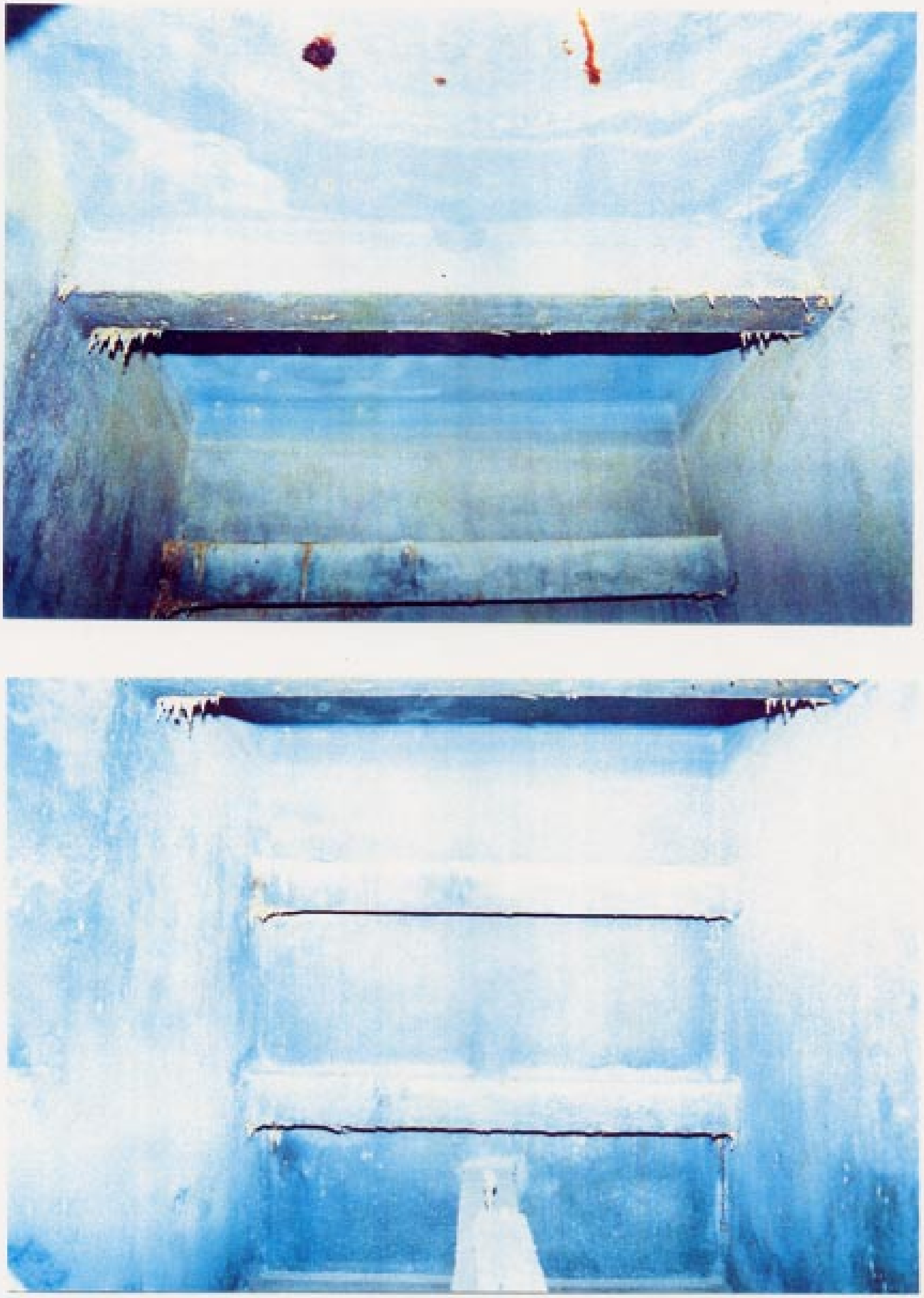
**PHOTGRAPH 8- SURFACE TOLERANT EPOXY B**



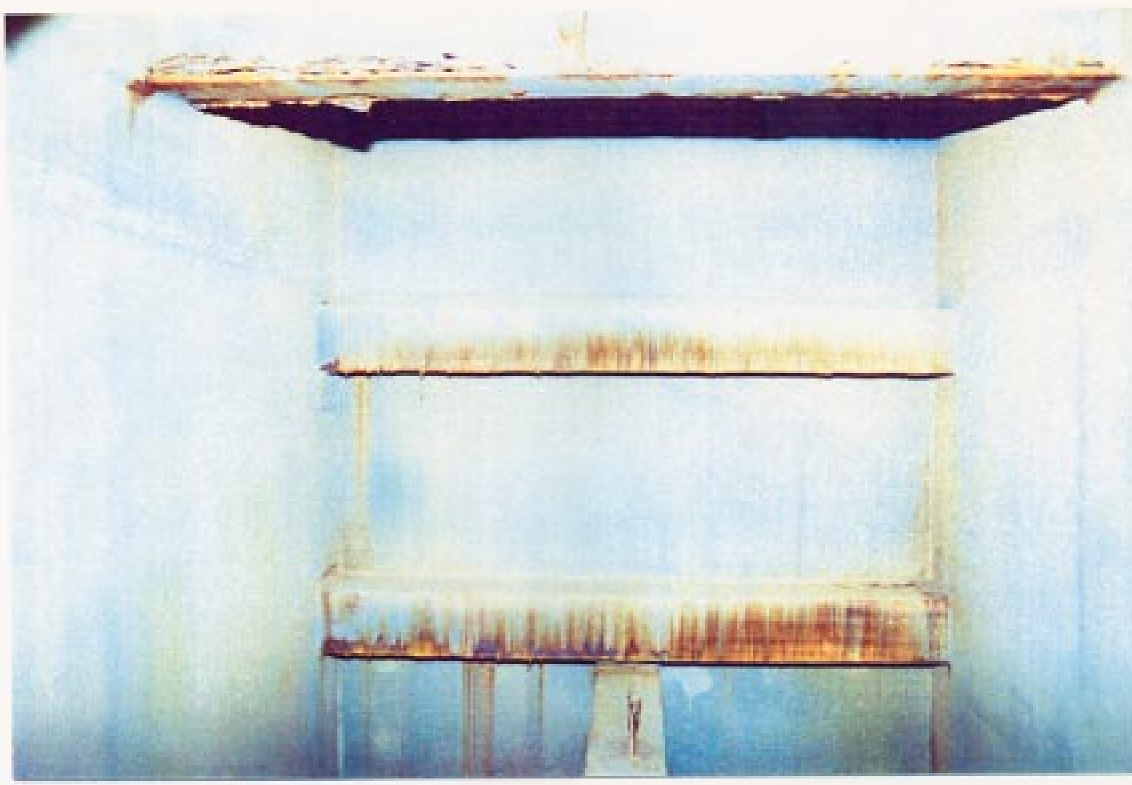
**PHOTOGRAPH 9- MIL-P-24441**

**PHOTOGRAPH 10-AGED EPOXY WITH ADDED ZINC ANODE**

**PHOTOGRAPH 11- PARTIAL COATING WITH ZINC ANODE**



**PHOTOGRAPH 12- SOLVENT BASED INORGANIC ZINC WITH ZINC ANODE**



**PHOTOGRAPH 13- SOLVENT BASED INORGANIC ZINC**

PHOTOGRAPH 14- HIGH RATIO WATERBORNE INORGANIC ZINC

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