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NSRP 0471

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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

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

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

in cooperation with
Peterson Builders, Inc.

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COMMITTEE
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July 1996
NSRP 0471

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

NEW SURFACE PREPARATION & COATING REPAIR TECHNIQUES IN BALLAST TANKS

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

in cooperation with
Peterson Builders, Inc.

PBI **PETERSON BUILDERS, INC.**

41 North Third Ave., Sturgeon Bay, Wisconsin 54235 (414) 743-5574, FAX (414) 743-3461

July 1996

Dear Shipbuilder,

Subject: SNAME Panel SP-3 Project 3-93-1 “NEW ***SURFACE PREPARATION & COATING REPAIR TECHNIQUES IN BALLAST TANKS"***

The enclosed report is the product of the National Shipbuilding Research Program (NSRP). ASSOCIATED COATINGS developed this information under the auspices of the Society of Naval Architects and Marine Engineers Ship Production Committee’s Surface Preparation and Coating Panel SP-3.

The ***NEW SURFACE PREPARATION & COATING REPAIR TECHNIQUES IN BALLAST TANKS*** objective was: “To determine which surface-tolerant coating systems can significantly reduce the cost of maintaining ship ballast tanks.”

After reviewing the enclosed report, please take time to complete and return the reader response card.

Sincerely,

John Meacham
Industrial Processes Program Manager

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

MAY 1996

PREPARED BY:
ASSOCIATED COATINGS CONSULTANTS, INC.
IN COOPERATION WITH
PETERSON BUILDERS, INC.
STURGEON BAY, WISCONSIN

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 Sixteen 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, a calcareous deposit forms which acts as a barrier, further reducing anode demand. As the coating fails with time, this process is repeated.

There are two coating systems in this project which utilize coatings combined with cathodic protection that have provided corrosion protection for sixteen years. Another system which consisted of a thin film, preconstruction zinc primer with zinc anode lasted for eleven years.

EXECUTIVE SUMMARY

Ship ballast tanks represent corrosion control nightmares. Ballast tanks are one of the most costly areas in which to apply coatings in both new ship construction and ship 'maintenance. Being subjected to intermittent wet and dry cycles of aerated sea water 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. Previous testing results are documented in NSRP Reports 0158, 0205, 0280, and 0332.

In 1988, the project was redirected to evaluate maintenance procedures and techniques. At that time the tanks had been under test for eight years. Included in this new project approach were current Volatile Organic Compound (VOC) compliant, surface tolerant epoxies from two suppliers, a new formulation of Mil-P-24441 (Formula 150/151), Type IV, VOC compliant epoxy, a soft coating, and a Japanese technique of adding a zinc anode (for cathodic protection) to an existing, partially failed coating in lieu of coating replacement. Both hand tool cleaning and abrasive blasting surface preparation techniques were evaluated. Two coating systems from the original project were still providing adequate protection and, therefore, left undisturbed.

After three additional years of testing, all but one of the systems were still providing corrosion protection. One of the two VOC compliant surface tolerant epoxies was essentially equal in performance over both the power tool cleaned and abrasive blast cleaned surface. The same was true for the second compliant epoxy except for the bottom of the hand cleaned tank which had excessive dry film thickness. The coating with the excessive thickness began to crack after one year and was totally delaminated at the end of three years. This coating and the same coating applied over abrasive blasted steel were repaired using hand and power tool cleaning techniques. The complete results of this program were reported in NSRP Report 0332.

In *1990*, funding was approved to continue the testing through December of 1992. In April 1991, one failed system was replaced with a waterborne inorganic zinc, and one 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. In April 1996, the present program completed three of testing for the replacement systems. This report summarizes the results of testing to date. All systems are still providing a reasonable degree of corrosion protection.

Table 2 contains a listing of all the systems presently being evaluated.

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CONCLUSIONS

This report includes the controlled testing results of nine different approaches to surface preparation and coating repair techniques for preservation of in-service ships ballast tanks utilizing VOC compliant coatings after three, five, eight, eleven, and sixteen 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. These 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 less costly surface preparation, i.e., hand and power tool cleaning, combined with surface tolerant coatings with special emphasis given to VOC compliant coatings. In the present program, the emphasis has 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 preconstruction primer combined with cathodic protection, a VOC compliant, single coat, inorganic zinc coating system with and without cathodic protection was selected for testing.

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

- The Epoxy "A" applied over the abrasive sweep blast cleaned surface is slightly better than the same system applied over a hand tool cleaned surface. Both systems are three years old.

- The repaired Epoxy "B" systems is providing adequate protection after eleven years. System was repaired at six and eight years.

Conclusions continued.

- The repaired, VOC compliant version of MIL-P-24441, Type IV (Formula 150/151) is providing acceptable corrosion protection after eight years.

- The waterborne high ratio inorganic zinc is beginning to fail after five years.

- The VOC compliant inorganic zinc coating systems with and without cathodic protection have very little failure after three years.

- Partial coating (Mil-P-23236) with fifty pound zinc anode system is still providing protection after sixteen years with only the flat bottom coating system and zinc anode being replaced at thirteen years.

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

- Fifty pound zinc anode addition to the six year old totally coated tank (Mil-P-23236) is providing extended protection without the necessity of coating repair/replacement. Original coating system applied in 1980.

- 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 reduction option provided the repairs are accomplished prior to total deterioration of the coating system.

1. TECHNICAL BACKGROUND

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

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 weight 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 anode (Galvalum III) anode lasted six years. The fifty pound zinc anode (Mil-A-18001H) lasted thirteen 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 salt muck provides a path for steel corrosion. Since the anodes are above the surface of the muck, no protection is provided during the deballast 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 sea Water, the cathodic protection system also causes a calcarious deposit to form over the bare steel areas. This calcarious deposit acts as a protective barrier and reduces the demand and depletion of the anode. Together, the coating and cathodic protection system are complimentary and increase the life of either system used independently. This point has been borne out in the test program.

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 an inorganic zinc coating (85% zinc in the dry film) are 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 topcoated. 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.

Volatile Organic compound (VOC) Compliant Coatings

New air quality management standards preclude the use of many of the formerly approved (Mil-P-23236) epoxy and zinc tank coating systems which do not meet existing VOC limits. 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 land fills. 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 surfaces which have been hand or power tool cleaned.

Two VOC compliant, surface tolerant epoxies were tested in this project. Eleven 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. Eight years ago another material (Epoxy "A") was also applied over the same two prepared 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.

Anodes Added to Existing Coated Tank

The Japanese 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 another eight to ten years. By replacing anodes as anode depletion occurs, the coating system life can extended for the life of the vessel.

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 deballasted 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.

Test Tank Facilities

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 dimensions of each tank assembly is 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 Photograph 1.

Following tank fabrication and application of each corrosion control system, the tanks were ballasted with fresh, natural sea water (See Table 1) and then de-ballasted. Each ballast cycle consisted of twenty days full and ten days empty.

TABLE 1 TEST SITE SEA WATER INFORMATION								
	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	18.5	4.2	17.8	4.2	7.6	5.2	9.4
Salinity (Parts per 1000)	18	29	22	36	6	33	19	27

Surface Preparation and System Application

Table 2 contains a listing of those systems currently under test to include surface preparation.

During abrasive blast surface preparation it was difficult to achieve a true SSPC-SP 10, "Near white Blast Clean" surface. Due to the high chloride contamination of the corroded steel, the blasted surface would flash rust within a matter of minutes. See Photograph 2. This statement holds true for all the tanks which were reblasted for this phase of the project.

No attempt was made to remove the chloride contamination other than that accomplished by the surface preparation technique. 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 volubility 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 surface roughness (profile) achieved for the Near White Blast Cleaned surface was 2.2 to 2.5 roils as measured in accordance with ASTM D 4417, Method C.

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 is shown in Photograph 3.

Hand (SSPC SP-2) and power tool cleaning (SSPC SP-3) consisted of chipping hammers, hand and power wire brushes, needle guns and power disc sanders. Hand sanding was used to feather the edge of intact remaining coatings. See photograph 4 for an example of the resultant surface preparation prior to the application Surface Tolerant Epoxy "A." Photograph 5 shows the repair surface preparation of the Mil-P-24441 system prior to spot priming and full refresher topcoat 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 6. Sharp edges were not rounded.

TABLE 2-TANK COATING SYSTEMS INCLUDED IN TEST PROGRAM

TANK NO.	SURFACE PREPARATION	ORIGINAL SYSTEM DESCRIPTION	ANODE	SYSTEM AGE	REPLACEMENT SYSTEM
1	SP-2/SP-3	SURFACE TOLERANT VOC COMPLIANT EPOXY "A"	NONE	3 YEARS	REPAIRED WITH SYSTEM PREVIOUSLY APPLIED. PREVIOUSLY APPLIED COATING ON FLAT OVERHEAD NOT REPLACED.
2	SP-10	TOTALLY COATED WITH TWO COATS OF AMINE ADDUCT CURED EPOXY (MIL-P-23236)	ZINC 50 #	16 YEARS 10 WITH ANODE	ZINC ANODE ADDED AFTER 6 YEARS.
3	SP-10	TOP AND BOTTOM SECTIONS COATED WITH TWO COATS OF AMINE ADDUCT CURED EPOXY (MIL-P-23236) CENTER LEFT UNCOATED.	ZINC 50 #	16 YEARS	ZINC ANODE REPLACED AFTER 12 YEARS. FLAT BOTTOM COATING REPLACED (SP2/3) AT 13 YEARS.
4	SP-7	SURFACE TOLERANT VOC COMPLIANT EPOXY "A"	NONE	3 YEARS	REPAIRED WITH SYSTEM PREVIOUSLY APPLIED.
5	SP-6	SURFACE TOLERANT VOC COMPLIANT EPOXY "B".	NONE	11 YEARS	THIS SYSTEM WAS SP-2 REPAIRED AFTER 6 YEARS AND 8 YEARS OF TESTING
6	SP-10	VOC COMPLIANT INORGANIC ZINC WITH ANODE	ZINC 12 #	3 YEARS	NEW SYSTEM
7	SP-10	VOC COMPLIANT EPOXY TANK COATING, MIL-P-24441, TYPE IV	NONE	8 YEARS	REPAIRED WITH SYSTEM PREVIOUSLY APPLIED. SP-2/SP-3 OF FAILED AREAS
8	SP-10	HIGH RATIO WATER BORNE INORGANIC ZINC	NONE	5 YEAR	NEW SYSTEM
9	SP-10	VOC COMPLIANT INORGANIC ZINC	NONE	3 YEARS	NEW SYSTEM

2. TEST RESULTS

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, bottom) and structure (top stiffener, top and bottom back stiffener, bottom stiffener, 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.

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 4 contains a summarv of the results from four different observers using the CLER technique. With the exception of Tank 8, the scores between observers are close.

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. Much of the data which is contained in the ASTM test report is included in the body of this report as summarized in Table 3. 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.

Table 3 contains a detail evaluation and rust grade for each graded tank and area. A cumulative score can be used to give an overall tank grade.

EPOXY "A" over Hand Cleaned Steel

After three years, the hand tool cleaned tank performed somewhat poorer than the sweep blast cleaned tank. At this stage in the project, it would be difficult to use the performance results of this system applied over hand tool cleaned steel verses the performance of the same system applied over abrasive blast cleaned steel to justify abrasive blasting. Both techniques are providing comparable protection to the steel during the test cycle. See photograph 8.

EPOXY "A" Over **Blast cleaned Steel**

Tank 4 has an overall ASTM rating of rust grade 9 with one area on the left side, bottom front quadrant graded as a 7. The performance of this system over Sweep Blast Cleaned (SP 7) steel is marginally better than the same system applied over hand and power tool cleaned steel. See photograph 9.

There is ***no*** edge breakdown on the top and back stiffeners with only minor breakdown on the bottom stiffener.

In summary, this system is providing good protection after three years. As discussed in the section on surface preparation and application, all edges and welds were stripe coated.

Repaired Epoxy "B"

The Epoxy "B" coated tank 5 has been under test for a total of eleven years. Following the initial six years of testing, this system was beginning to show significant breakdown. The top of the tank had twenty-five to fifty percent failure. 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, 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 only spot repaired at this time.

After three additional years of testing (eleven total), the top overhead and top back stiffener has 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. See photograph 10.

VOC Compliant Version of Mil-P-24441

Except for some edge breakdown on the top overhead stiffener, the coating system in Tank 7 is providing corrosion protection after eight years of testing. The overall failure is less than one percent. See photograph 11.

Aged Coating System with Added Zinc Anode

No change was noted in Tank 2 since the last report. No new coating failure was detected. Calcareous deposits continue to increase. Very little anode consumption was noted. This system **is** sixteen years old. A zinc anode was added after six years. See photograph 12.

Zinc Anode with Partial Coatings

After sixteen years of testing, Tank 3 is still providing protection to 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 (5o 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 beginning to fail. No significant metal loss was detected on the flat sides and overhead. The stiffener thicknesses loss ranged from 1/8 inch on the back top stiffener to 1/16 on the other stiffeners. The original thickness was 1/4 inch. See photograph 7 showing repaired and recoated bottom prior to re-exposure. Photograph 13 shows performance results to date.

VOC Compliant Solvent Based Inorganic Zinc With and Without Cathodic Protection

Both Tank Six (with 12 pound zinc anode) and Tank Nine (with no anode) are demonstrating essentially the same performance with Tank Six being somewhat better. It is still too early to form conclusions about the relative benefit of zinc anodes in extending coating system life at this point. See Photographs 14 and 15.

Waterborne Zinc Over Blast Cleaned Steel

The high ratio inorganic zinc coating applied in Tank 8 has been under test for five years. This system is beginning to fail. The top overhead stiffener has failed with edge exfoliation. The top back stiffener has also failed. The balance of the flats range from rust grade 7 to 8. See photograph 16.

3. PROJECT BENEFITS

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

- 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.

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

- Verification that full thickness inorganic zinc with or without cathodic protection can significantly extend the repair or replacement cycle for ballast tank coating systems.

- Verification that total removal of an existing coating system is not necessary when performing tank coating maintenance.

TABLE 3-TANK TEST RESULTS

TANK ONE	COATING SYSTEM: SURFACE TOLERANT EPOXY A VOC COMPLIANT (AMERON 385P/385). (SYSTEM LIFE-3 YEARS) COATING NOT REPLACED IN OVERHEAD. SURFACE PREPARATION: SP-2/SP-3 PREVIOUS SYSTEM: SAME
TOP-FLAT DFT-N/A	RUST GRADE 8 CLER CONDITION # 2
TOP-STIFFENER DFT-N/A	EDGE BREAKDOWN, RUST GRADE 6 CLER CONDITION # 2
BACK-FLAT DFT-14.5 MILS	RUST GRADE 8 CLER CONDITION # 2
BACK-TOP STIFFENER DFT-9.8 MILS	RUST GRADE 7 CLER CONDITION # 2
BACK-BOTTOM STIFFENER DFT-26 MILS	RUST GRADE 7 CLER CONDITION # 2
BOTTOM-FLAT DFT-22.7MILS	RUST GRADE 9. FRONT RIGHT QUADRANT CRACKING AT WELD. CLER CONDITION # 2
BOTTOM-STIFFENER DFT-19 MILS	RUST GRADE 9. GOOD EDGE PROTECTION. CLER CONDITION # 2
BOTTOM-FRAME DFT-16.2MILS	RUST GRADE 9 CLER CONDITION # 2
RIGHT SIDE DFT-13.3 MILS	RUST GRADE 8 CLER CONDITION # 2
LEFT SIDE DFT-15 MILS	RUST GRADE 9 CLER CONDITION # 2

TABLE 3-TANK TEST RESULT (CONTINUED)

TANK TWO	COATING SYSTEM: MIL-P-23236 COATING WITH ZINC ANODE (SYSTEM LIFE-15 YEARS) ORIGINAL DRY FILM THICKNESS RECORDED AS 6.5 to 8.5 MILS. SURFACE PREPARATION: SP-10 PREVIOUS SYSTEM: ANODE ADDED AFTER 6 YEARS OF TESTING
TOP-FLAT	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. CLER CONDITION # 4
TOP-STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. 3/16 INCH THICKNESS REMAINING CLER CONDITION # 4
BACK-FLAT	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. CLER CONDITION # 4
BACK-TOP STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. NO SIGNIFICANT METAL LOSS. CLER CONDITION # 4
BACK-BOTTOM STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. NO SIGNIFICANT METAL LOSS. CLER CONDITION # 4
BOTTOM-FLAT	BEGINNING TO SCALE. SCALE WORSE THAN LAST GRADE PERIOD. NEEDS REPAIR. CLER CONDITION # 4
BOTTOM-STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 4
BOTTOM-FRAME	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. 1/8 INCH THICKNESS REMAINING. CLER CONDITION # 4
RIGHT SIDE	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD CLER CONDITION # 4
LEFT SIDE	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD CLER CONDITION # 4

TABLE 3-TANK TEST RESULT (CONTINUED)

TANK THREE	COATING SYSTEM : MIL-P-23236 PARTIAL WITH ZINC ANODE (SYSTEM LIFE-16 YEARS). DRY FILM THICKNESS FOR COATED AREAS RECORDED AS 6 TO 9.5 MILS. SURFACE PREPARATION: SSPC-SP-10 INITIAL/SP-2 REPAIR OF BOTTOM PREVIOUS SYSTEM: ANODE REPLACED TWELVE YEARS. REPAIRS MADE TO FLAT BOTTOM
TOP-FLAT	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. CLER CONDITION # 2
TOP-STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. CLER CONDITION # 1
BACK-FLAT	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4, PAINTED AREA-CLER CONDITION # 1
BACK-TOP STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. 1/8 INCH THICKNESS REMAINING. UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4
BACK-BOTTOM STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4
BOTTOM-FLAT	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-STIFFENER	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. SOME EDGE EXFOLIATION. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 3
BOTTOM-FRAME	NO DETECTABLE CHANGE FROM LAST GIUDE PERIOD. SOME EDGE EXFOLIATION. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 3
RIGHT SIDE	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4. PAINTED AREA CLER CONDITION # 1
LEFT SIDE	NO DETECTABLE CHANGE FROM LAST GRADE PERIOD. UNPAINTED AREA (CALCAREOUS SCALE)-CLER CONDITION # 4. PAINTED AREA CLER CONDITION # 1

TAELE 3-TANK TEST RESULT (CONTINUED)

TANK FOUR	COATING SYSTEM: SURFACE TOLERANT EPOXY A VOC COMPLIANT (AMERON 385P/385) (SYSTEM LIFE-3 YEARS) SURFACE PREPARATION: SP-7 PREVIOUS SYSTEM: SAME OVER SP-10
TOP-FLAT DET-16.2 MILS	RUST GRADE 10 CLER CONDITION # 1
TOP-STIFFENER DFT-13.6 MILS	RUST GRADE 9. NO EDGE BREAKDOWN. EDGE OF STIFFENER 1/8 INCH THICK TAPERING UP TO FULL THICKNESS. CLER CONDITION # 1
BACK-FLAT DFT-15.8 MILS	RUST GRADE 9. SOME RUST STREAKS. CLER CONDITION # 2
BACK-TOP STIFFENER DFT-18.2 MILS	RUST GRADE 9. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 2
BACK-BOTTOM STIFFENER DFT-14.4 MILS	RUST GRADE 9. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 2
BOTTOM-FLAT DFT-19.8 MILS	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-STIFFENER DFT-17 MILS	RUST GRADE 9. MINOR EDGE BREAKDOWN. 3/16 INCH THICKNESS REMAINING. CLER CONDITION # 1
BOTTOM-FRAME DFT-15 MILS	RUST GRADE 9. 1/16 INCH THICKNESS REMAINING ON FLANGE EDGE; 3/16 INCH THICKNESS REMAINING ON WEB. CLER CONDITION # 1
RIGHT SIDE DFT-13.1 MILS	RUST GRADE 9 CLER CONDITION # 1
LEFT SIDE DFT-14.9 MILS	BOTTOM FRONT QUADRANT 7. BALANCE 9 CLER CONDITION # 2

TABLE -3.-TANK. TEST RESULT (CONTINUED)

TANK FIVE	COATING SYSTEM: SURFACE TOLERANT SYSTEM B (DEVOE 235) (SYSTEM AGE 11 YEARS) SURFACE PREPARATION : SP-2 MINOR AREAS ONLY @ 8 YEARS PREVIOUS SYSTEM: SYSTEM "B" W/SP-6. SP-2 REPAIRED @ 6 AND 8 YEARS.
TOP-FLAT DFT-14.4 MILS	RUST GRADE 10. CLER CONDITION # 1
TOP-STIFFENER DFT-15.3 MILS	EDGE BREAKDOWN. RUST GRADE 9 BALANCE. NO SIGNIFICANT METAL LOSS. 75% OF EDGE HAS FAILED. CLER CONDITION # 3
BACK-FLAT DFT-18 MILS	RUST GRADE 9. CLER CONDITION # 1
BACK-TOP STIFFENER DFT-21.8 MILS	TOP OF STIFFENER IS DELAMINATING AND LIFTING. BALANCE RUST GRADE 9. NO SIGNIFICANT METAL LOSS. CLER CONDITION # 3
BACK-BOTTOM STIFFENER DFT-22.4 MILS	RUST GRADE 9. No SIGNIFICANT METAL LOSS. CLER CONDITION # 1
BOTTOM-FLAT DFT-16.4 MILS	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-STIFFENER DFT-	RUST GRADE 9. NO SIGNIFICANT METAL LOSS. CLER CONDITION # 1
BOTTOM-FRAME DFT-24.9 MILS	RUST GRADE 9. NO SIGNIFICANT METAL LOSS. CLER CONDITION # 1
RIGHT SIDE DFT-16.7 MILS	RUST GRADE 7. LOWER LEFT QUADRANT FAILED. THIS SAME AREA HAS FAILED EACH TIME A NEW COATING SYSTEM HAS BEEN APPLIED. CLER CONDITION # 2
LEFT SIDE DFT-12.3 MILS	RUST GRADE 8 CLER CONDITION # 2

TABLE 3-TANK TEST RESULT (CONTINUED)

TANK SIX	COATING SYSTEM : VOC COMPLIANT INORGANIC ZINC W/ ZINC ANODE (CARBO ZINC llHS) (SYSTEM LIFE-3 YEARS) SURFACE PREPARATION: SP-10 PREVIOUS SYSTEM: PRECONSTRUCTION ZINC PRIMER W/ZINC ANODE (SIGMA)
TOP-FLAT DFT-13 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS. SOME OF THE DEPOSITS ARE FLAKING OFF WITH ZINC VISIBLE UNDER THE FLAKED AREA. NO RUST. CLER CONDITION # 1
TOP-STIFFENER DFT-9.5 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BACK-FLAT DFT-13.3 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BACK-TOP STIFFENER DFT-12.3 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BACK-BOTTOM STIFFENER DFT-11.7 MILS	RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BOTTOM-FLAT DFT-9.5 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BOTTOM-STIFFENER DFT-10.2 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BOTTOM-FRAME DFT-7.6 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
RIGHT SIDE DFT-9.7 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
LEFT SIDE DFT-	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1

NOTE: VERY LITTLE ANODE DEMAND.

TANK 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 3 YEARS. TOTAL 8 YEARS) SURFACE PREPARATION: SP-2/3 PREVIOUS SYSTEM: SAME W/SP-10 SURFACE PREPARATION
TOP-FLAT DFT-7.7 MILS	RUST GRADE 9 CLER CONDITION # 1
TOP-STIFFENER DFT-11.8 MILS	BREAKDOWN ON EDGES. RUST GRADE 8 BALANCE. CLER CONDITION # 2
BACK-FLAT DFT-12.9 MILS	TOP AND CENTER-RUST GRADE 10. BOTTOM RIGHT-RUST GRADE 7. RUST GRADE 10 BALANCE OF BOTTOM. CLER CONDITION # 1
BACK-TOP STIFFENER DFT-14.6 MILS	RUST GRADE 8 CLER CONDITION # 2
BACK-BOTTOM STIFFENER DFT-17.3 MILS	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-FLAT DFT-16.6 MILS	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-STIFFENER DFT-13.6 MILS	RUST GRADE 9 CLER CONDITION # 1
BOTTOM-FRAME DFT-15 MILS	RUST GRADE 7 CLER CONDITION # 2
RIGHT SIDE DFT-15.8 MILS	RUST GRADE 9 CLER CONDITION # 1
LEFT SIDE DFT-14.9 MILS	RUST GRADE 9 CLER CONDITION # 1

TABLE 3-TANK TEST RESULT (CONTINUED)

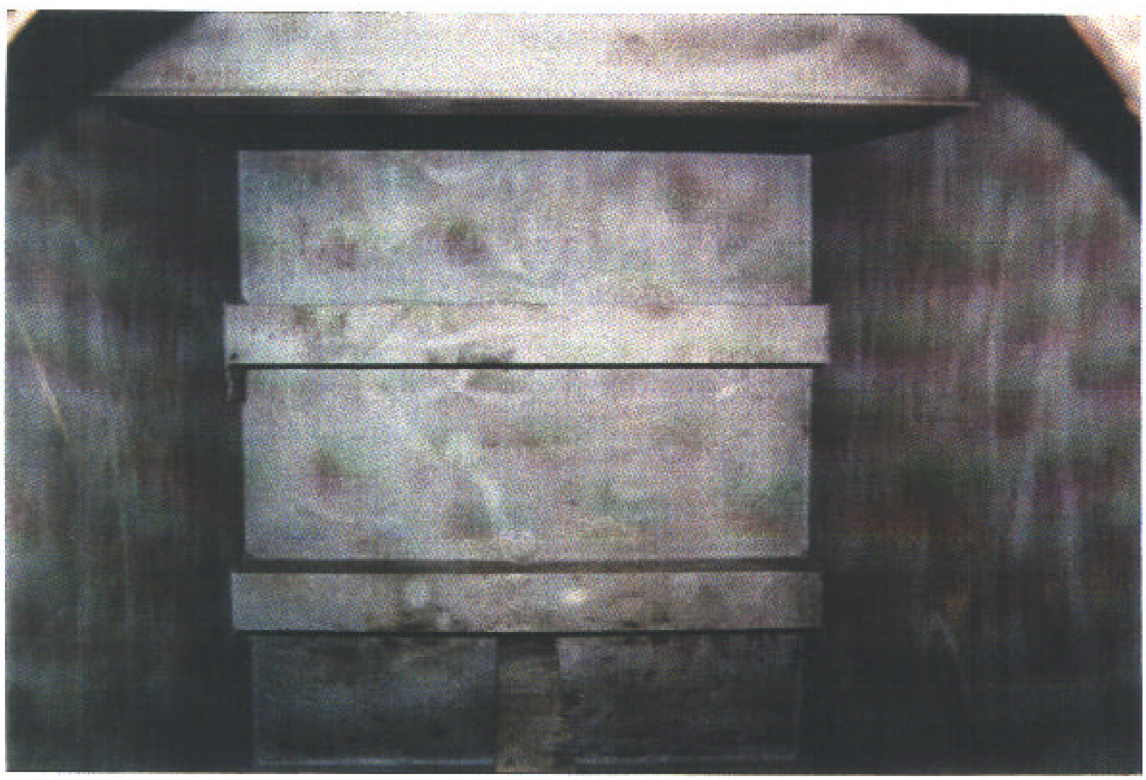
TANK EIGHT	COATING SYSTEM: WATERBORNE HIGH RATIO INORGANIC ZINC (INORGANIC COATINGS) SURFACE PREPARATION: SP-10 PREVIOUS SYSTEM: SAME. (SYSTEM LIFE FIVE YEARS)
TOP-FLAT DFT-7.2 MILS	RUST GRADE 9 CLER CONDITION # 1
TOP-STIFFENER DFT-	EDGE BREAKDOWN WITH EXFOLIATION. LEFT HALF FAILED. RIGHT HALF AND BACK SIDE RUST GRADE 8. CLER CONDITION # 3
BACK-FLAT DFT-7.8 MILS	RUST GRADE 9 WITH RUST STREAKING. CLER CONDITION # 2
BACK-TOP STIFFENER DFT-	TOP FAILED. RUST STREAKING. STEEL DELAMINATION/EXFOLIATION FROM RUST UNDER INORGANIC ZINC COATING. CLER CONDITION # 4
BACK-BOTTOM STIFFENER DFT-	EDGE FAILURE. BALANCE RUST GRADE 8. CLER CONDITION # 3
BOTTOM-FLAT DFT-9.4 MILS	RUST GRADE 7 CLER CONDITION # 3
BOTTOM-STIFFENER DFT-	RIGHT SIDE FAILED. LEFT SIDE BEGINNING TO BREAKDOWN. BALANCE RUST GRADE 8 ON LEFT SIDE; RUST GRADE 4 ON RIGHT SIDE. CLER CONDITION # 4
BOTTOM-FRAME DFT-	BACK SIDE RUST GRADE 7. FRONT SIDE RUST GRADE 6. TOP RUST GRADE 10. UNDERSIDE OF FLANGE TOTAL FAILURE. CLER CONDITION # 3
RIGHT SIDE DFT-5.6 MILS	BOTTOM FRONT FAILED 6 INCHES UP FROM BOTTOM. BALANCE RUST GRADE 9. CLER CONDITION # 2
LEFT SIDE DFT-7.4 MILS	RUST GRADE 8 CLER CONDITION # 2

TANX NINE	**COATING SYSTEM : VOC COMPLIANT INORGANIC** ZINC (NO ANODES) (CARBO ZINC llHS) (SYSTEM LIFE-3 YEARS) SURFACE PREPARATION: SP-10 PREVIOUS SYSTEM: SURFACE TOLERANT SYSTEM B
TOP-FLAT DFT-13.9 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
TOP-STIFFENER DFT-9.1 MILS	RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. SOME EDGE FAILURE BEGINNING. CLER CONDITION # 2
BACK-FLAT DFT-9.2 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BACK-TOP STIFFENER DFT-11.9 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BACK-BOTTOM STIFFENER DFT-7.3 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BOTTOM-FLAT DFT-11.7 MILS	RUST GRADE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
BOTTOM-STIFFENER DFT-8.5 MILS	AREA APPROXIMATELY 6 INCHES BY 4 INCHES ON RIGHT SIDE DELAMINATED WITH CALCARIOUS DEPOSIT UNDER THE DELAMINATED AREA. ZINC VISIBLE UNDER DELAMINATED AREA. BALANCE RUST GRADE 10. CLER CONDITION # 2
BOTTOM-FRAME DFT-8.5 MILS	FRONT RUST GRADE 6. BACK RUST GIUDE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 2
RIGHT SIDE DFT-8.2 MILS	RUST GRADE 9 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1
LEFT SIDE DFT-8.4 MILS	RUST GIUDE 10 WITH SOME CALCARIOUS DEPOSITS FORMING AT PINHOLES. CLER CONDITION # 1

TABLE 4-COMPARISON OF CLER INSPECTION RESULTS

TANK N	T p	S de	B m	T Bars	Total	Top	Sides	Bottom	T Bars	Total
Ob e e Wheele						Observer-McCullom				
Tw										
h										
S										
Eight	1	1	2	3	7	1	1	1	2	5
Nine	1	1	1	2	5	1	1	1	1	4
O s mmer						Observer-Fultz				
One	1	2	1	2	6	2	2	2	2	8
Two	[illegible]	[illegible]	[illegible]	[illegible]	13	4	4	4	4	16
S										
S										
E gh										
N										

PHOTOGRAPH 1-TEST TANK ASSEMBLIES

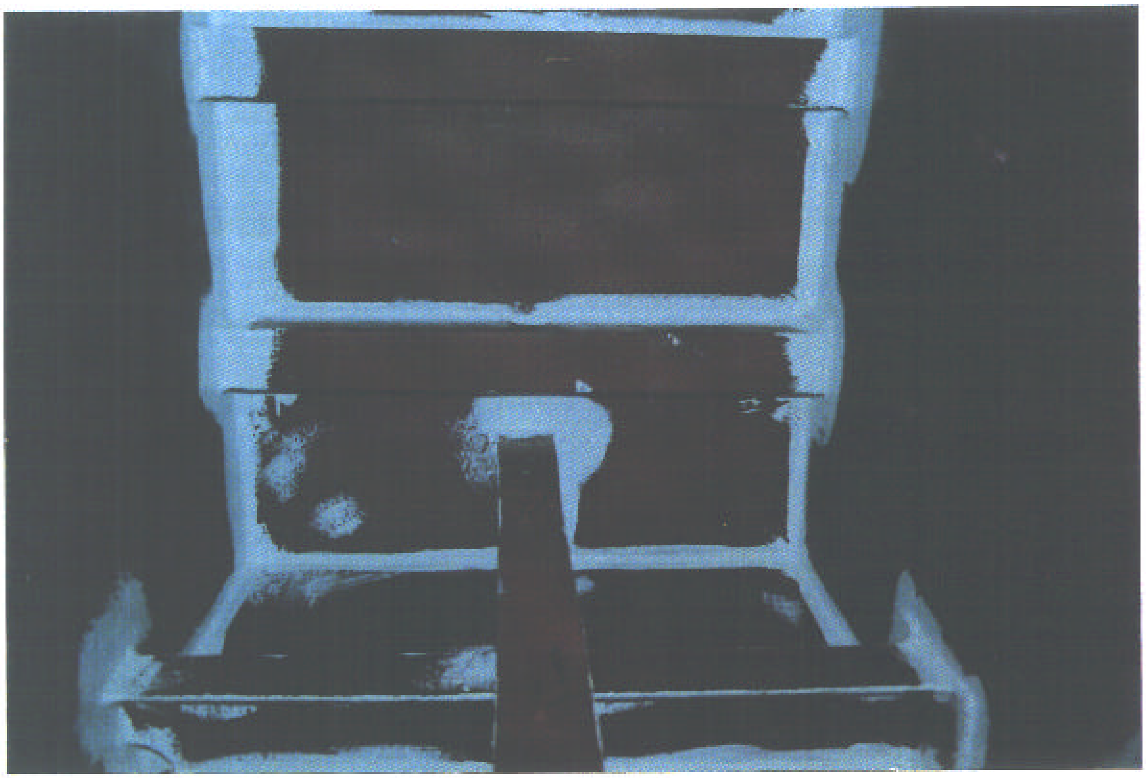


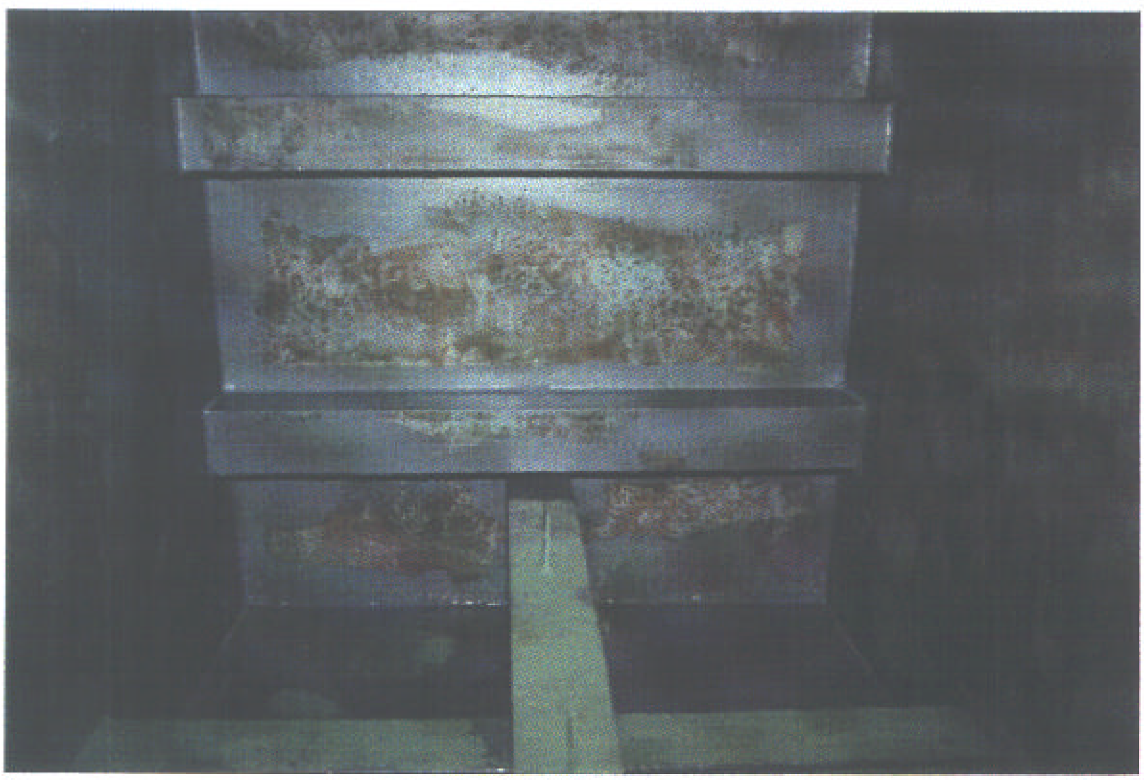
PHOTOGRAPH 2-NEAR WHITE BLAST SHOWING FLASH RUST

PHOTOGRAPH 3-SWEEP BLAST CLEANED SURFACE PRIOR TO COATING

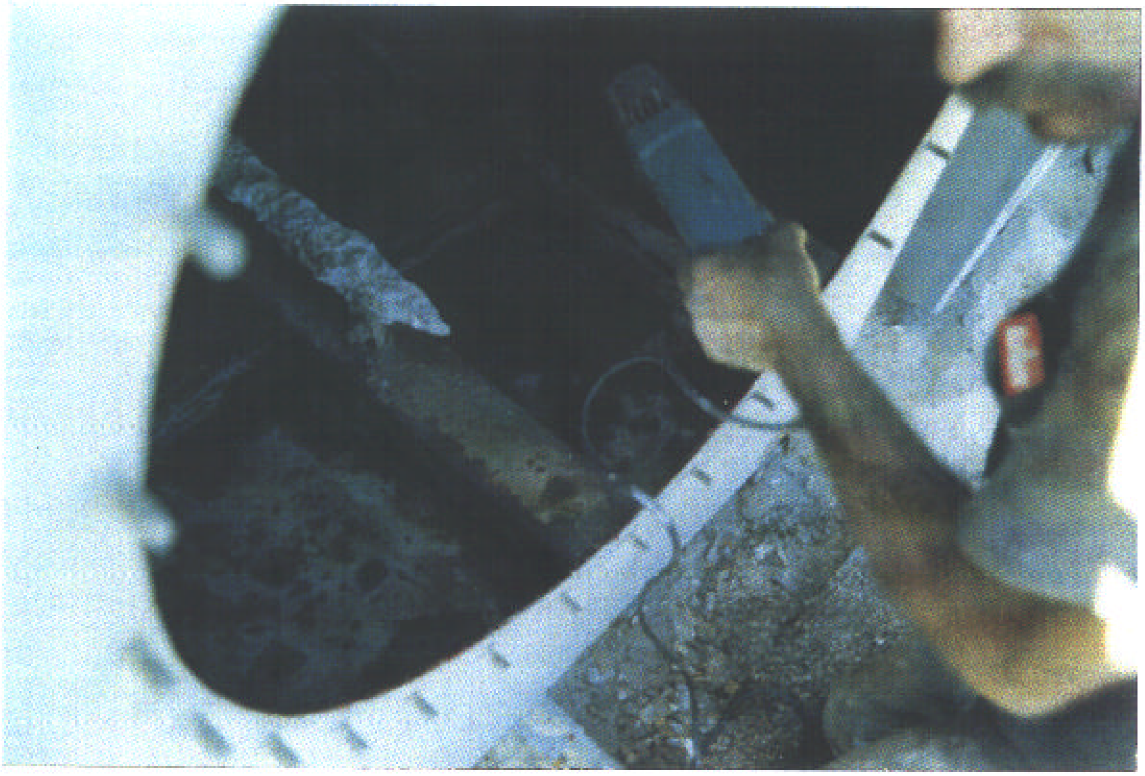
PHOTOGRAPH 4-POWER/HAND TOOL CLEANED SURFACE PRIOR TO COATING

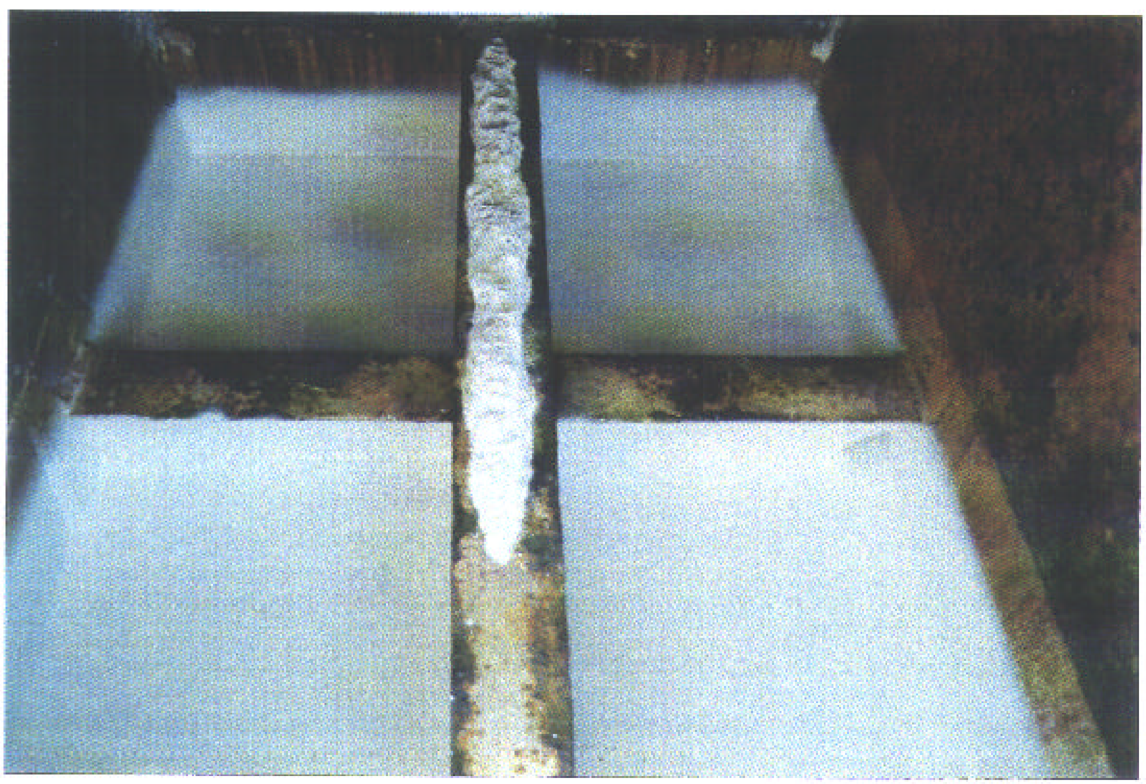
PHOTOGRAPH 5-SURFACE PREPARATION OF INTACT MIL-P-24441



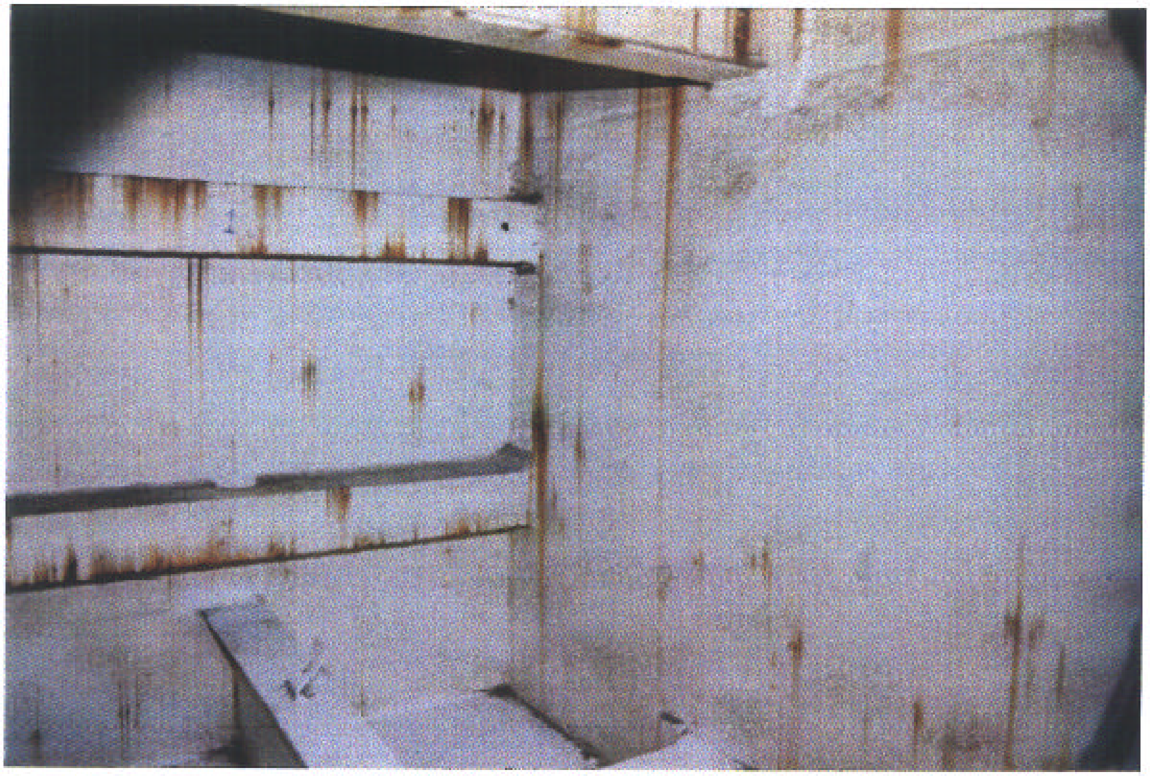


PHOTOGRAPH 6-STRIPE COATING BETWEEN COATS



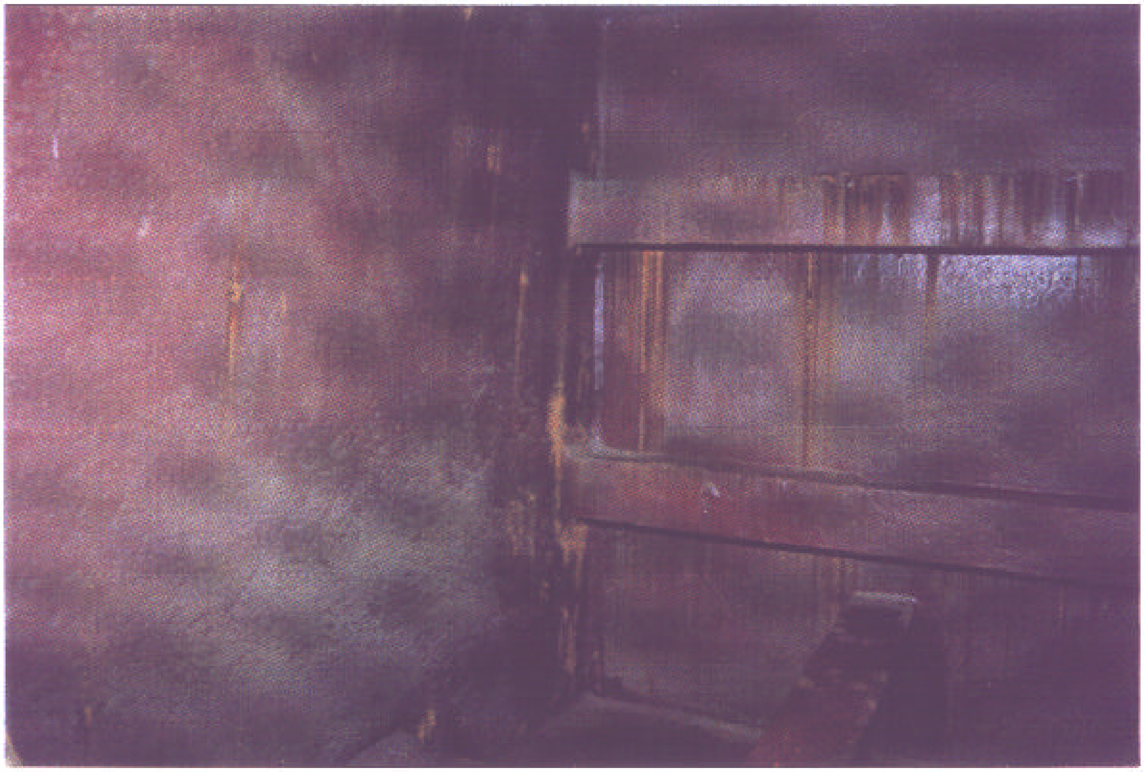


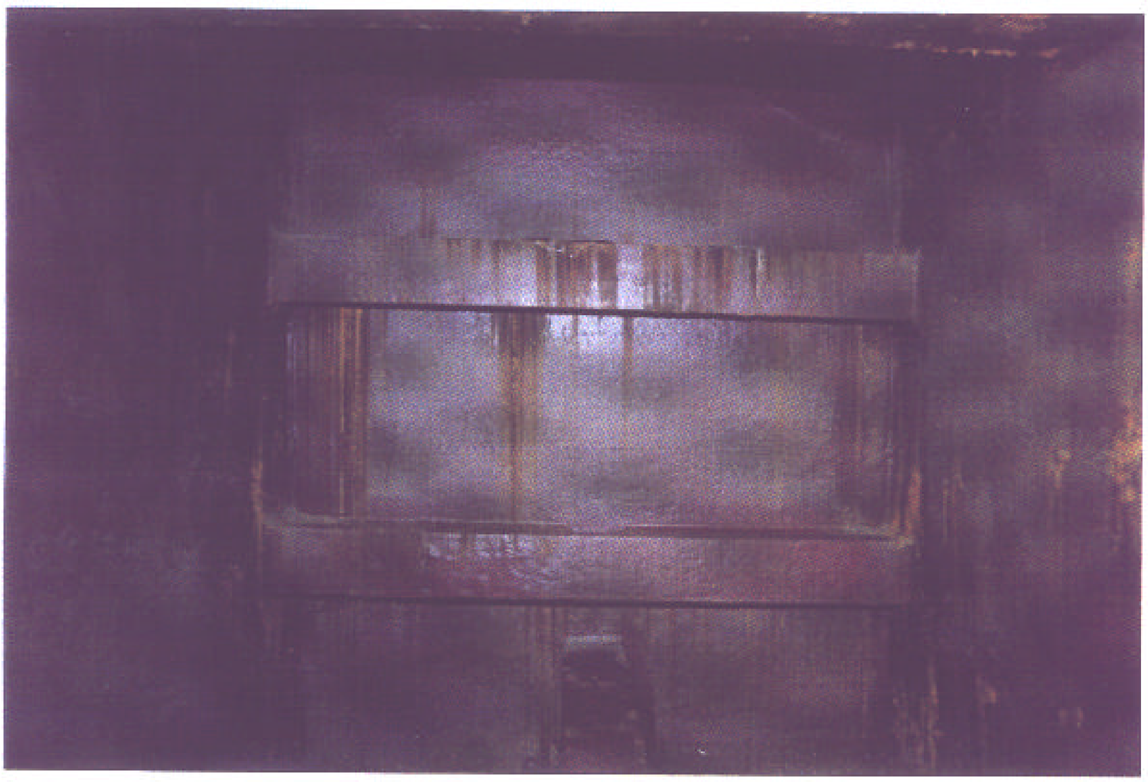
PHOTOGRAPH 7-REPAIRED BOTTOM OF PARTIALLY COATED TANK WITH CP



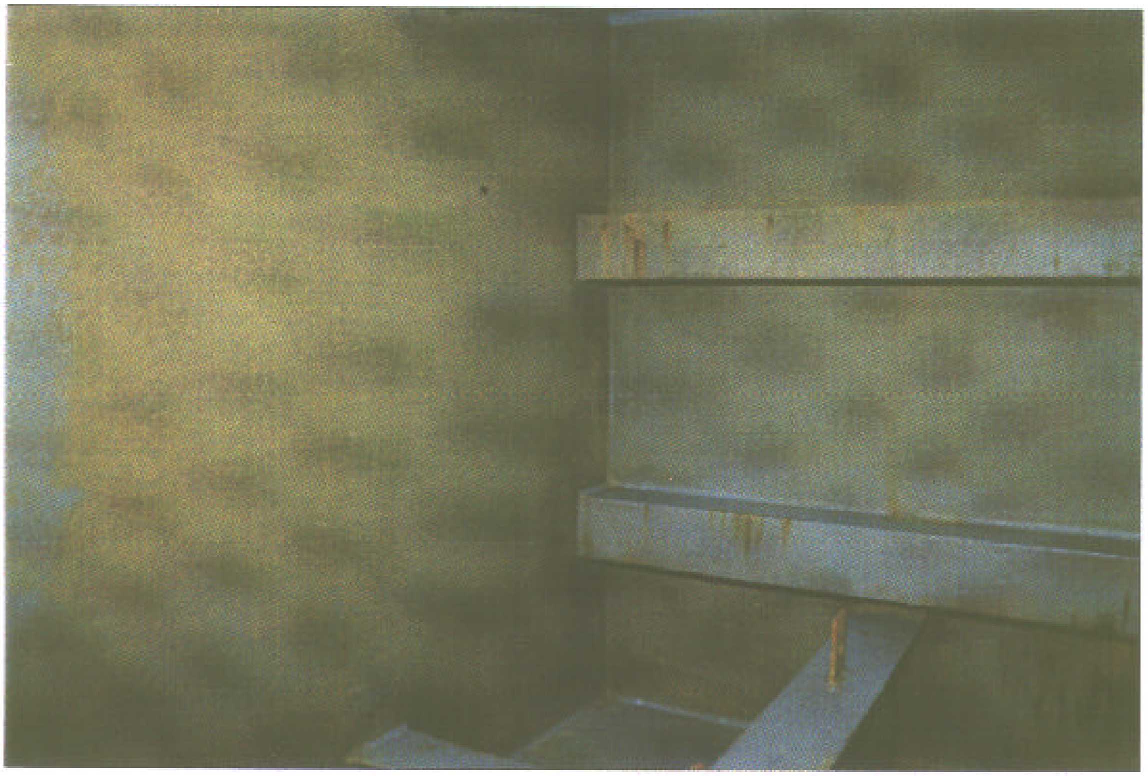
PHOTOGRAPH 8- SURFACE TOLERANT EPOXY "A" OVER HAND TOOL CLEANING

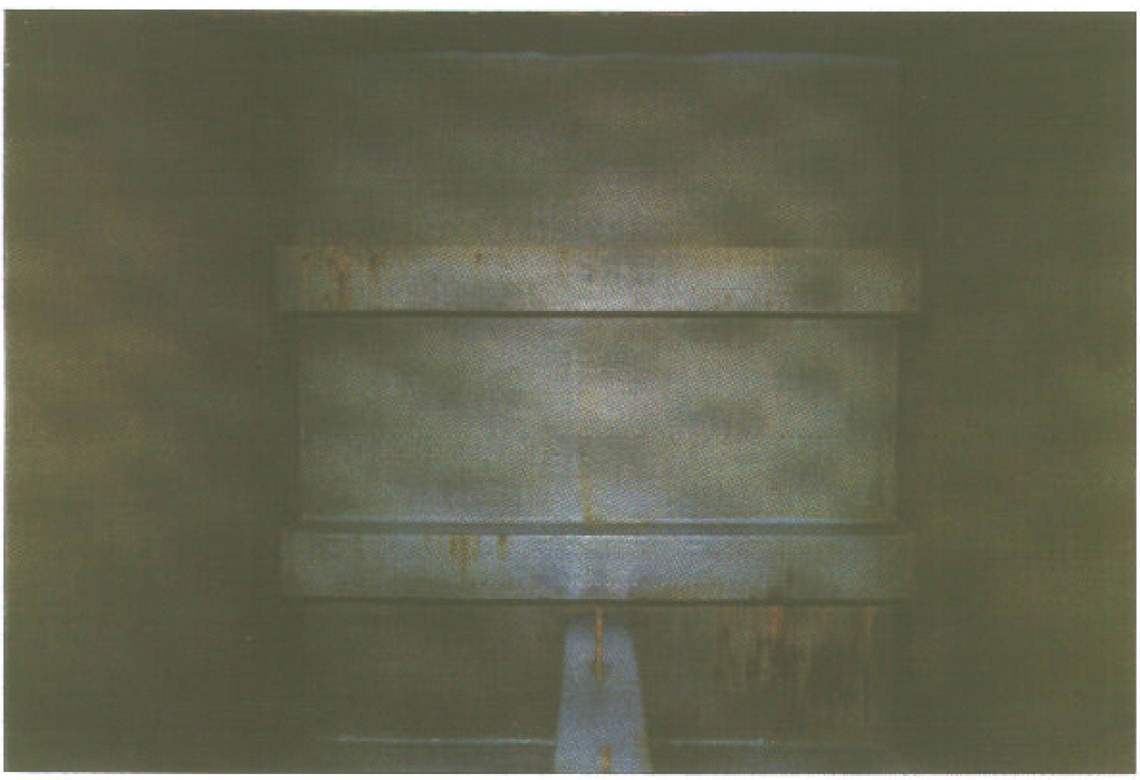
PHOTOGRAPH 9-SURFACE TOLERANT EPOXY "A" OVER SWEEP BLAST CLEANING



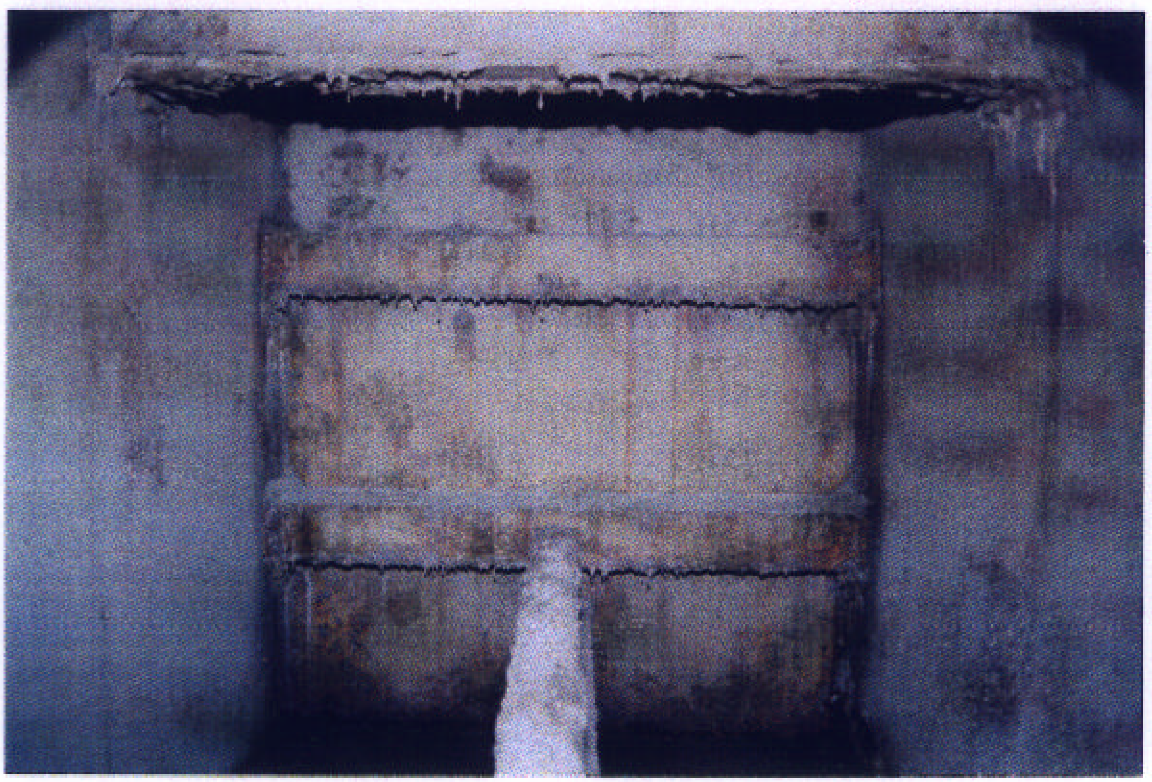


PHOTOGRAPH 10-REPAIRED SURFACE TOLERANT EPOXY "B"



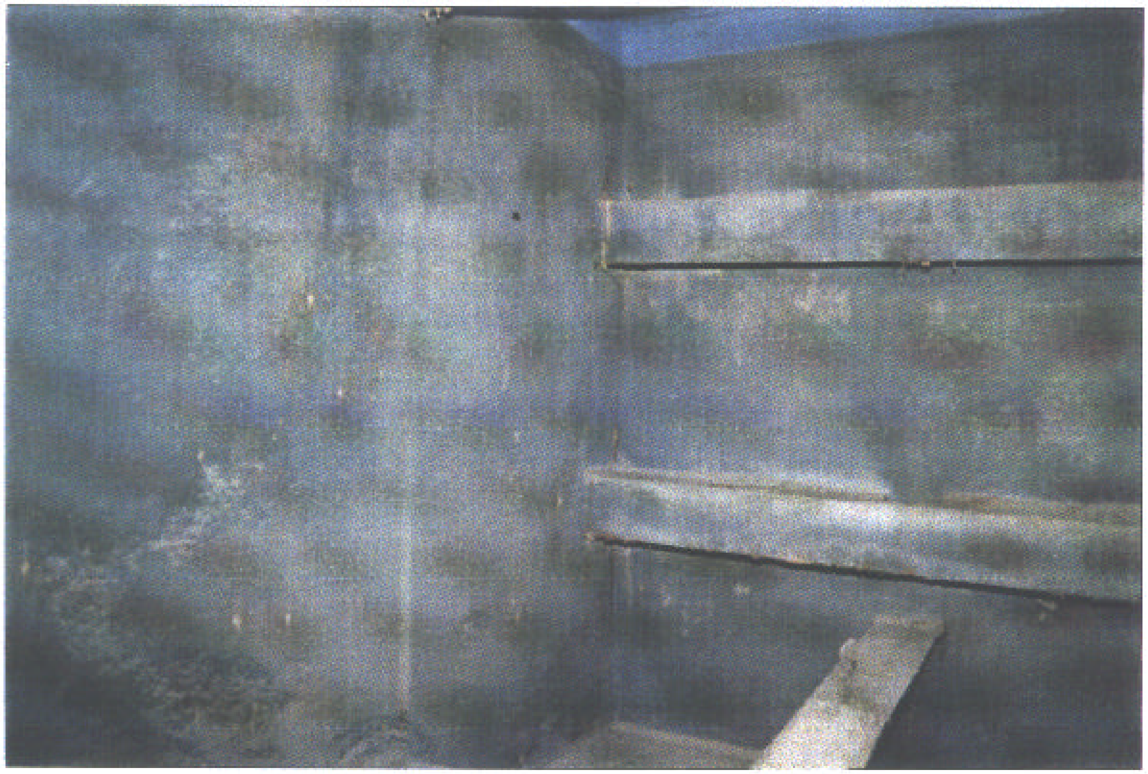


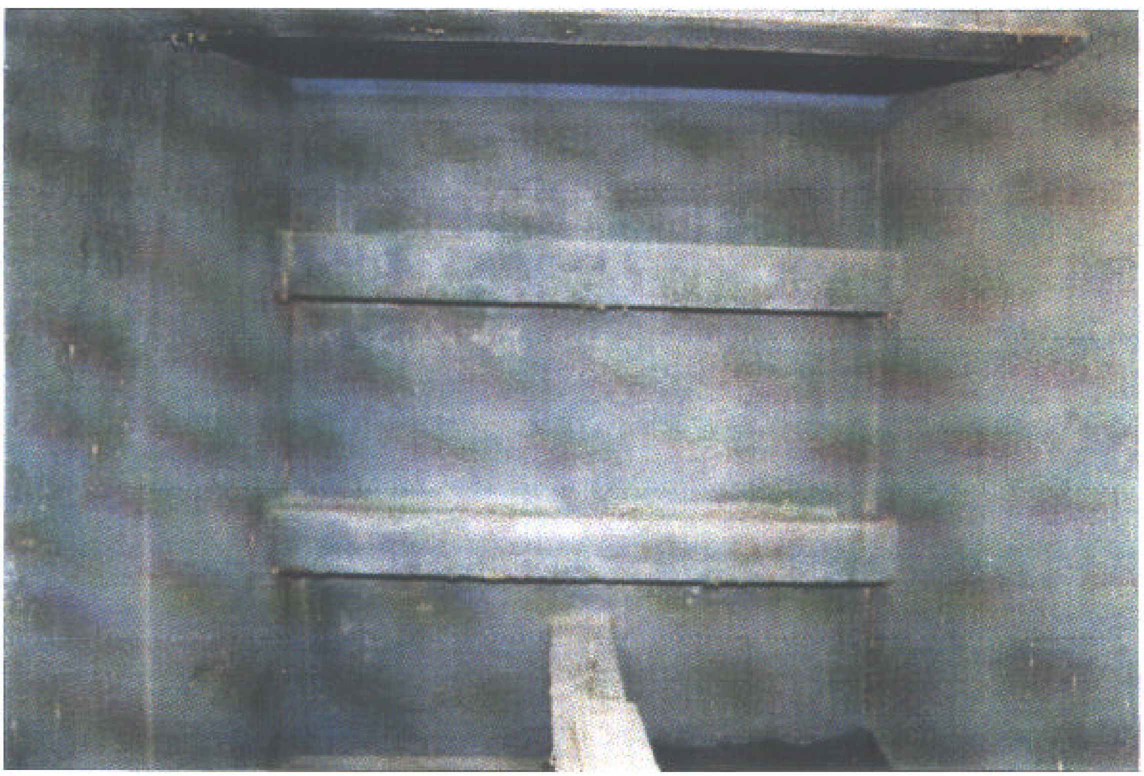
PHOTOGRAPH 11-REPAIRED AND OVERCOATED MIL-P-24441



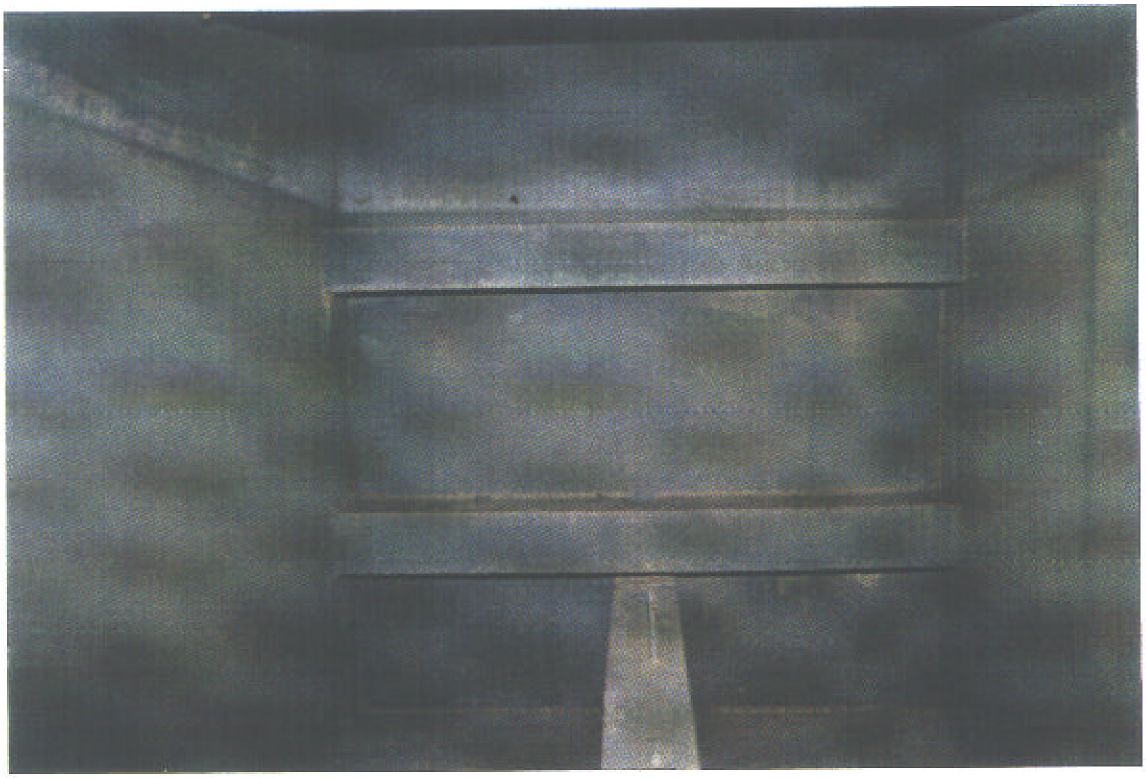
PHOTOGRAPH 12-AGED COATING (MIL-P-23236) WITH ADDED ZINC ANODE

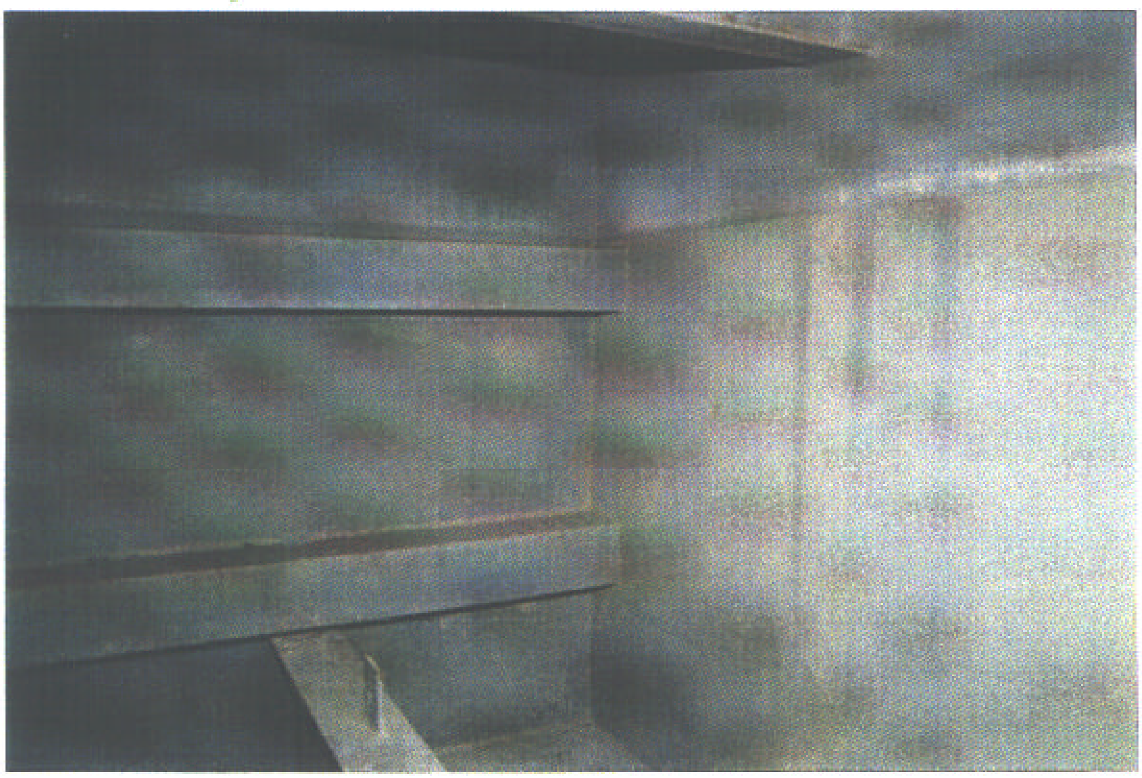
PHOTOGRAPH 13-PARTIAL COATINGS (MIL-P-23236) WITH ZINC ANODE



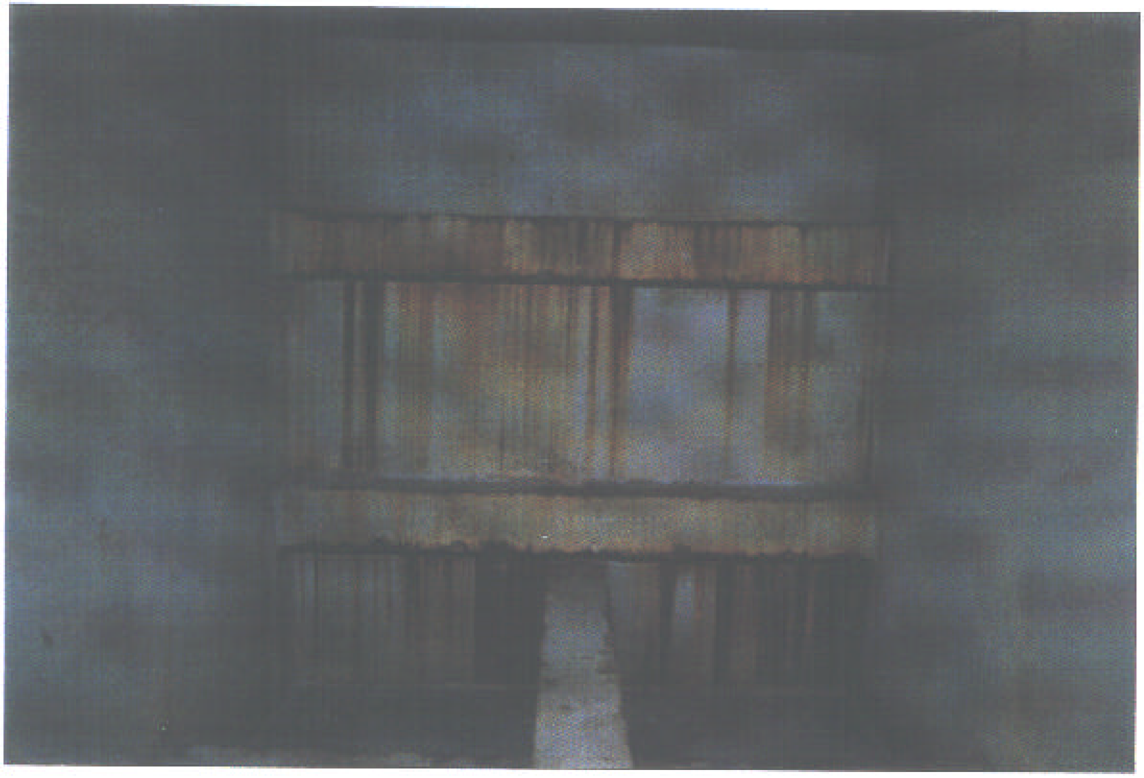


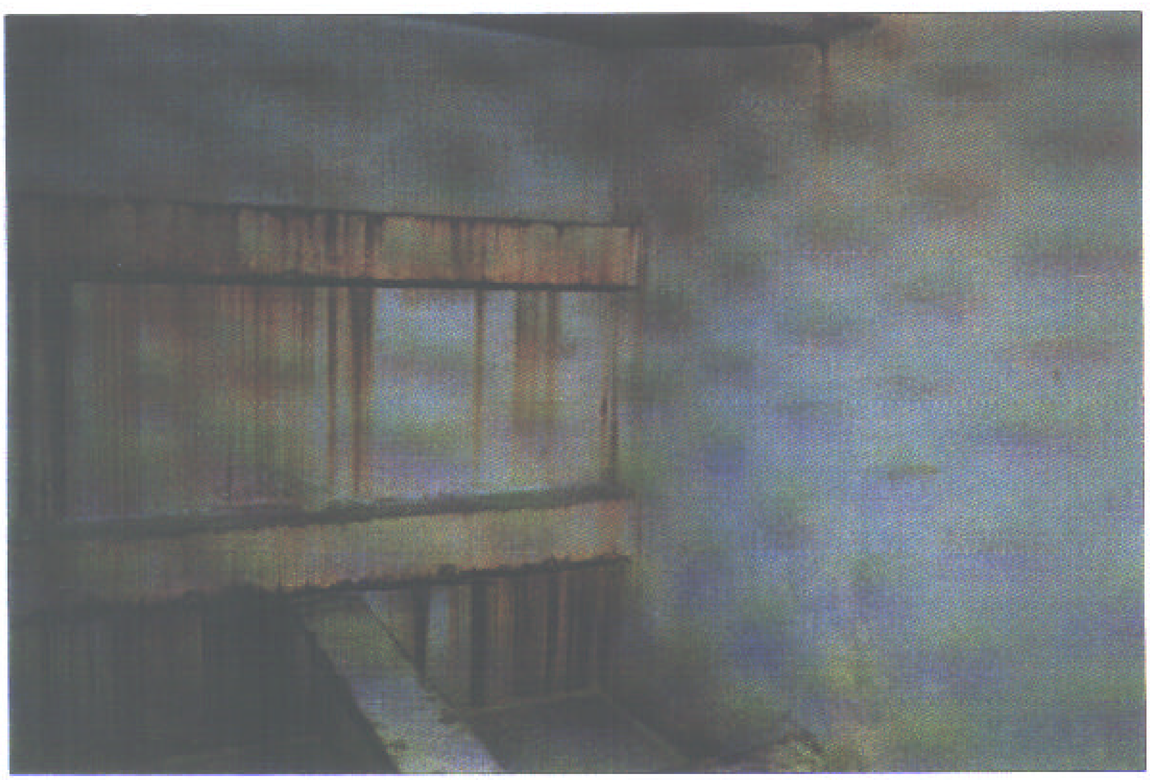
PHOTOGRAPH 14-SOLVENT BASED INORGANIC ZINC WITH ZINC ANODE





PHOTOGRAPH 15-SOLVENT BASED INORGANIC ZINC





PHOTOGRAPH 16-HIGH RATIO INORGANIC ZINC

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