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LEAD- AND CHROMATE-FREE ANTICORROSIVE PRIMERS, HIGH SOLIDS, 100 PERCENT SOLIDS, AND WATERBORNE COATINGS AS ENVIRONMENTALLY SOUND COATINGS FOR RECLAMATION INFRASTRUCTURES

September 1994
Technical Service Center

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The Bureau of Reclamation investigated VOCs (volatile organic compounds) and toxic materials in protective coatings, beginning with a study of the replacement of red lead primer by lead- and chromate-free anticorrosive primers. The next investigation featured high solids and 100 percent solids coatings for immersion or buried applications. Tightening VOC regulations created a need for replacement coatings for Reclamation's VR-3 and VR-6 vinyl coating systems, and brought about the investigation of waterborne coatings as alternatives to currently specified solvent-borne coatings. The probable advent of regulations restricting the VOC contents of all types of coatings added urgency to all investigations. The investigations were conducted using testing procedures appropriate to the exposures the coatings being tested would experience under field conditions. Acceptable alternative coatings systems to those currently specified, but which faced difficulties because of tightening regulations, emerged from the investigations. Many acceptable alternative coating systems require as much or more care in surface preparation and the use of more sophisticated application techniques and equipment than the systems they will replace. The rapid rate of technical and regulatory change makes the institution of a Reclamation-wide integrated and coordinated protective coatings program desirable.

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by

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September 1994

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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INTRODUCTION

Protective coatings are and have been Reclamation's main defense against corrosion and other forms of degradation for both metallic and nonmetallic materials. On immersed or buried steel surfaces, protective coatings are often used in conjunction with CP (cathodic protection). Although alternative means of fighting corrosion, such as the use of intrinsically corrosion-resistant materials, has not been neglected, economic and engineering considerations have limited the use of this approach to date.

The proliferation of environmental and health regulations has sounded the death knell for traditional high VOC (volatile organic compound) and heavy metal containing coatings. Some of these coatings, including Reclamation's high performance VR-3 and VR-6 vinyl coatings systems for immersion service, and Federal Specifications TT-P-86, type IV Red Lead Primer for atmospheric exposure service, have outstanding anticorrosive properties which are difficult to match. VR-3 and VR-6 vinyl coatings systems have inescapably high VOC contents while, as its name suggests, TT-P-86, type IV Red Lead Primer, contains red lead pigment in abundance. Other traditional types of coatings are being affected or eliminated as well. Stringent health and safety regulations have caused the near disappearance of coal-tar enamel as a field-applied, high performance coating and a general decline in its overall use. Coal-tar enamel is a near unique coating and is the only one for which a 50-year service life (assuming proper maintenance) can be claimed based on actual experience. Yet another casualty is TT-P-636, an alkyd oxide-chromate primer. TT-P-636 is a "garden variety" primer which has been used for many years as the standard primer for coating steel in atmospheric exposure service. The presence of chromates in its pigmentation has caused its elimination.

Reclamation anticipated the coming of more stringent and universal HS&E (health, safety, and environmental) regulations well over a decade ago and sought out more environmentally safe coating systems to replace the lead component and high VOC components of the old coating systems. Both of these components were very important parts of the traditional coating systems and were what made these coatings so effective. Their discontinued use is having a big impact on the protective coatings industry, and is leading to the development of a myriad of new coating systems. As a result, investigations were instituted to acquire data on possible replacements for the standard types of coatings being routinely specified at that time.

These investigations were divided into three investigative series to address the three main types of coatings; the red lead replacement (RLR) series, the high solids and 100 percent solids (X) series for immersion service, and the waterborne replacements for solventborne coatings (W) series for non-immersion service. The investigations have been conducted primarily as a part of the former PRESS (Project Related Engineering and Scientific Studies) and the subsequent WATER (Water Technology and Environmental Research) programs. This report is a compilation and discussion of the data gathered and the conclusions drawn from the more recent investigations conducted under the PRESS and WATER programs. This report is not a "final" product, because the WATER program is ongoing and the necessity for further investigation continues. Three main investigations were instituted to discover replacement coatings which had comparable performance characteristics to the established coatings they were expected to replace:

1. A lead- and chromate-free anticorrosive primer investigation to replace the existing TT-P-86G, type IV red lead and TT-P-636D alkyd oxide-chromate primers for atmospheric exposure service (RLR series).

2. A high solids (solvent-borne) and 100 percent solids high performance and immersion service coatings investigation to replace

coatings such as VR-3, VR-6, and coal-tar enamel (or, if need be, coal-tar containing coatings in general) (X series).

3. An investigation to study waterborne coatings as low VOC replacements for currently specified solvent-borne nonimmersion (atmospheric exposure) coatings (W series).

All three investigations had strong HS&E components. In addition, they had performance components connected with economics. The object was not only to discover coatings which had acceptable HS&E characteristics (a must), but also to discover which had relatively low cost per square meter (foot) per year of satisfactory service (life-cycle) costs as well. Modern high performance and waterborne types of coatings have been available for several decades. However, HS&E factors have led to their increasing use despite their sometimes higher initial costs. Increasing use and HS&E regulations have spurred coatings manufacturers to develop new and improved versions of these coatings.

Management Implications

The ultimate purpose of the investigations was to obtain knowledge and data that could be used to constantly update specifications, particularly guide specifications such as Reclamation's C-1000 and C-1001 (Reclamation, 1994). Laboratory tests, no matter how carefully conceived and executed, are still conducted under laboratory conditions and can only attempt to mimic actual exposure conditions in an accelerated manner (Grossman, 1977). At present, only real-life exposures under conditions of actual use can establish the true performance characteristics of a coating system. In the future, this characteristic may change (Greenfield, 1994). The accelerated tests in the laboratory are conducted to screen out obviously unsuitable candidates for field testing and to discover coating(s) systems which show a corresponding promise for success. Consequently, coatings investigations are a continuous process of laboratory and field testing in which feedback plays an important, although sometimes neglected, part. The data acquired from laboratory and field testing form the basis of a coatings management program. A sound coatings management program has as its objective the protection of structures which require protective coatings at the lowest long term cost and with minimum disruption to operations, consistent with sound HS&E practices. Historically, Reclamation coating management has been a field office activity, although a regional office often had some involvement. The Denver Office provides technical support to these offices, one facet of which is the type of centralized laboratory investigations previously described and which form the basis of this report.

CONCLUSIONS

1. Satisfactory replacements are available for TT-P-81, type IV Red Lead Primer and TT-P-636 Alkyd Oxide-Chromate Primer. Both will be replaced by the lead- and chromate-free anticorrosive primers. The replacement primers tested in the RLR testing series performed well. Since the date they were tested, some additional established "or equal" primers of the same type have been applied in the field successfully. At least one of the tested red lead replacement primers is now available in an equal performance higher solids, lower VOC alternative version. An additional lead- and chromate-free anticorrosive primer, TT-P-664D, was tested less extensively as part of a solvent-borne control system in the W series. It showed a tendency toward brittleness in the mandrel bend test and it is being closely watched in the exterior exposure test. This primer, along with those previously mentioned, is now in Reclamation guide specifications. The most widely chosen options to date have been Systems No. 2 and 3. They, like the System No. 2W TT-P-664D primer, have a phenolated alkyd binder system. Next, in terms of interest, have been the CALTRANS formulations PB-201 and PB-202. These

formulations have a cold-cut phenolic varnish binder system. The anticorrosive pigment in all of the lead- and chromate-free primers tests was zinc phosphate. At this point, lead- and chromate-free type primers are Reclamation's new "standards" and the RLR project has proved more successful than originally expected or hoped for. However, assuming properly prepared steel substrates, it remains to be seen if long term durability of the new, more HS&E friendly, primers will equal the TT-P-86, type IV primer in long term durability and corrosion resistance. Experience has shown that the new primers will exceed the TT-P-636 Chromate containing primer in performance.

2. The regulations governing the use of coatings, including VOC limitations, are becoming ever more restrictive. Some regulators are aiming at eventually obtaining a goal of zero percent VOC. VOC considerations were never absent in selecting the coatings systems to be tested in the investigations being reported. In July 1993, negotiators on a Government/industry committee sponsored by the EPA (Environmental Protection Agency) *tentatively* agreed to propose that industrial maintenance coatings applied in the field be restricted to 350 g/L (2.92 lb/gal). It is important to note that this figure applies to the coatings as *applied*, not as supplied. Assuming the process continues without any serious problems, the rule will be subjected to public comment sometime in 1994 and could become effective in 1996. VOC levels for other AIM (architectural and industrial maintenance) coatings were also *tentatively* agreed upon as well as future VOC reduction strategies (SSPC News, 1993). These levels would be national rules and hopefully, would supplant the confusion caused by the myriad of State and local rules now in effect.

The effect on the coatings systems tested for this report should the 350-g/L (2.92-lb/gal) rule be placed in effect would, fortunately, not be very extensive. Most affected would be the RLR coatings and the W series control alkyds. Only the CALTRANS solvent-borne primer formulas and TT-P-664D (as supplied) would meet the new restrictions. The other lead- and chromate-free primers and the TT-E-490E silicone-alkyd topcoats would not. The others possibly could be reformulated to meet the new restrictions, but this task could be difficult and might require special application equipment. The W series emulsion coatings systems would be in compliance, as would all the X series high solids solvent-borne, at least as supplied, and 100 percent solids coatings systems would also be in compliance.

3. The most promising coatings in the X series were Systems No. 1X, 2X, 3X, 4X, 5X, 6X, 8X, 13W, 9X, 10X, and 11X. System No. 1X is a cracker tar extended aromatic polyurethane for shop application that was chosen for testing because this type of coatings system has attracted industry interest as a pipe coating and is 100 percent solids. System No. 2X is a 100 percent solids epoxy. Systems No. 3X and 6X are high solids types of epoxies. System No. 8X is System No. 6X with a compatible aliphatic polyurethane topcoat from the same coatings manufacturer system. These coatings systems were chosen for testing because of their good reputations and/or the good reputations of their manufacturers. System No. 5X is a hydrocarbon modified epoxy-polyamide which is claimed to be a less toxic alternative to standard coal-tar epoxies. It was chosen for testing because of this property and the results showed it to be equal to or better than coal-tar epoxy in performance. System No. 13W is a breakthrough coating, a waterborne epoxy which passed 3,000+ hours of immersion in both salt water and fresh water. As previously mentioned, waterborne technology is one method of handling the VOC problem. All of the coatings mentioned to this point are two-package types.

The remaining Systems No. 4X, 9X, 10X, and 11X are of a separate type. These systems are one-package, moisture-cure polyurethanes. The curing agent, or second package, is moisture from the air. An advantage of these coatings is their rapid cure. Time before immersion after the final coat has been applied at 10 °C (50 °F) and 50 percent relative humidity is one-third of a day. Most two-package epoxy systems require a minimum of 7 days at 20 °C (70 °F). Field experience to date has shown that the moisture-cure polyurethanes tested have good adhesion to existing VR-6 vinyl-coated hydraulic structures and can be used as repair coatings. This property has significance for the future, when in all likelihood, vinyls will disappear because of VOC regulations (the number of vinyl coatings manufacturers is already shrinking). As for specific moisture-cure polyurethane systems tested, System No. 9X consisted of a zinc-rich primer, a micaceous iron oxide containing aromatic intermediate coat, and a micaceous iron oxide containing aliphatic topcoat. System No. 10X consisted of multiple coats of a micaceous iron oxide containing aromatic refined tar. Systems No. 10X and 11X consisted of a micaceous iron oxide containing aromatic primer and intermediate coat and a micaceous iron oxide containing aliphatic topcoat. System No. 10X, the micaceous iron oxide containing aromatic refined tar system, has shown some indication that it might withstand exposure to direct sunlight. A field test, preferably a Reclamation field test confirmed by field tests conducted by others, will be required before Reclamation's current ban on the use of bituminous containing materials in direct sunlight will be open to an exception.

All of the X series coatings systems mentioned are now included in Reclamation guide specifications. A brief mention is in order for those coatings systems not specified. They did not "fail." They either had better alternatives within the X series or some problem that may have been caused by the application process. System No. 7X was not specified because the manufacturer of the coatings system preferred the specified System No. 6X for long term water immersion. The good performance of System No. 6X in the testing process made it the mutually preferred of the two low VOC systems. System No. 12X had a bad floating problem on incompletely prepared panels. Its resistance to water immersion was satisfactory and its adhesion was very good. Although System No. 12X will not yet be placed in the guide specifications, an appropriate field trial would be considered.

4. The W series investigations blazed a new trail for Reclamation coatings. Although TT-P-19, an acrylic emulsion coating for exterior wood and masonry, has been used on Reclamation structures for many years, no acrylic emulsion coatings for steel had been considered, which is not surprising because the technology required to make satisfactory emulsion coatings for steel is of relatively recent origin and is still developing. As a result of the W series investigations, three (counting System No. 13W, which was also reported on as a part of the X series) all waterborne coatings systems now exist for metal in the guide specifications. Some other waterborne coatings systems are possible candidates for future inclusion in the Reclamation guide specifications. Conclusions regarding these coatings systems will be included.

System No. 5W performed well and a variation of it is now in the guide specifications. The variation specifies use of the topcoat only because it can be a primer as well as a finish coat. Conversations with the manufacturer have established that our specification is fine for whites and light colors. For deep colors, System No. 5W should be used and their sales outlets have been instructed to furnish System No. 5W whenever a deep color or "tone" is ordered. Reclamation guide specifications will be modified to reflect this knowledge and reduce the chance of error. System No. 16W was placed in the guide specifications because of its good performance in the laboratory and exterior exposure (EE) tests. System No. 16W is a semigloss coating system with a separate primer.

System No. 17W, a gloss system with the same primer from the same manufacturer, tested poorly both in the laboratory and in EE. This result was surprising. It was subsequently learned that Systems No. 16W and 17W are separate and distinct formulations. System No. 17W is now undergoing reformulation.

Among the possible candidates for future inclusion in the specifications are Systems No. 10W and 15W. System No. 10W has a waterborne zinc-rich primer, an acrylic (with adhesion promotor added) intermediate coat, and an acrylic topcoat. Information has been received from outside contacts in the coatings field that modification of standard spraying equipment is required for successful application of the waterborne zinc-rich primer. Until this knowledge is more widely disseminated, or until some successful Reclamation field trials on at least a limited number of sites have been completed, this coatings system will be "available," but not specified. System No. 15W has a separate acrylic primer and an acrylic topcoat. As with System No. 10W, performance in laboratory and EE testing (1 year) has been good. However, two samples of both the primer and topcoat exhibited fissuring shortly after application. The term "fissuring" is used instead of "crawling" because the process did not leave the surface uncoated (Federation of Societies for Coatings Technology, 1978). A thinly coated area was surrounded by areas of normal thickness creating a shallow canyon like effect. A third sample of each was satisfactory. The difference between the samples which showed fissuring and the ones which did not was caused by the different weather conditions present when they were shipped. Those samples shipped during the cold weather of winter exhibited the problem and the one shipped during the warm weather of late spring/early summer did not. Consequently, this coating system has not yet been placed in the Reclamation guide specifications. A decision will be made as to whether to include it in the guide specifications with a caveat or to have it "available," but not specified, after further EE.

5. Color is not a purely aesthetic wild card with a variety of coatings systems. It can and often does influence coatings properties. This characteristic is especially true where a white or tint base has had large quantities of tinting color dispersions added to it. These color dispersions must be compatible with a range of formulations within a specific generic group. Large additions of tinting dispersions can dilute the base coating and change its properties. Lightfastness is another problem. If less lightfast pigments are required to make the color, particularly if those pigments are expensive, both an increase in cost and a decrease in quality will be experienced. With high solids and 100 percent solids coatings systems, custom colors should not be used unless a compelling reason exists for their use. If reasonably large initial and touchup quantities are involved, they may not present a serious problem. For the small to medium volume coatings users (which Reclamation facilities will be in the future), obtaining these colors is not difficult or costly for a reasonably large initial quantity. However, obtaining small quantities of the colors several years later for touchup can be expensive because most coatings manufacturers will require a minimum order of 94 liters (25 gal). Work is in progress in the coatings industry to develop mechanized small batch tinting capability for high solids, high performance coatings. However, as of the time this report was written, the status of this work is unknown. Because specific "universal" color dispersions are used for tinting alkyds or emulsions, the custom color problem is less severe. However, as previously mentioned, quality problems can develop with dark colors.

No solution to the color problem will please everyone or be completely foolproof.

However, steps can be taken to ameliorate the problem. The following actions are not new, but they can be reasonably effective:

a. Order from the coatings manufacturers' standard color cards. It may help to get an assurance that the colors which are chosen will be available in touchup quantities for the foreseeable future.

b. If appearance is important in exterior exposure, consider lightfastness and durability when choosing colors. Colors made using metal oxide pigments are generally less expensive and more light stable than those made with organic pigments, although organic pigments are continuously being improved. If appearance is not important and standard epoxies, for example, are being used in direct sunlight, the freshly applied color will be faded and mottled in a matter of months. Consequently, relatively inexpensive colors are more desirable than more costly ones.

c. When doubt exists about which general color to choose for a feature which is in exterior exposure and direct sunlight, three colors should be at least considered. These colors are: white, beige, and neutral gray.

White has the advantage of being always available and less obtrusive when touched up. When chalking is present, white will still look like white and the effects of the chalking will be less noticeable. A disadvantage of white is its tendency to show dirt, rust stains, etc., to a greater degree than other colors. This characteristic is good for inspection purposes, but not so desirable aesthetically.

Beige comes in different depths of shade. Light and light-to-medium depths are best. Beige fits in well with desert backgrounds and does not show dirt, rust stains, etc., as much as does white. Because beige contains "earth" colors, such as iron oxides, they have a more subdued "natural" look than white or some other colors. A drawback, although it is aesthetically pleasing, is that the onset of corrosion will be less visible.

Neutral grays can vary from almost white to almost black. The most suitable ones are the light-to-medium shades. Neutral grays do not clash with other colors or natural backgrounds and have a subdued appearance. They do not show dirt, rust stains, etc., as much as white, but the onset of corrosion is more visible than with beige.

6. Applied research and guide specifications revisions are continuing, not discrete, activities. All facets of coatings technology are undergoing an indefinite period of accelerated change. Consequently, Reclamation's coatings program must also be geared to changing conditions.

7. A Reclamation-wide, integrated coatings program is recommended. This program should be coordinated by the coatings specialist within the soon to be established TSC (Technical Services Center). Field office coordinators would transmit coatings information through regional office coordinators to the TSC and receive coatings information, either directly or through the regional coordinators, in return. The most important pieces of information that the field offices would be transmitting are the results of the coatings inspections conducted by their respective field offices. The Reclamation coordinator would analyze and consolidate these reports and distribute the results (perhaps at sometime in the future, electronically) back to the field offices and regional coordinators. This type of system would permit the performance of new versus established coatings systems (or the performance of different new coatings systems) to be tracked. This system would improve the TSC coatings program by making available to all within Reclamation the type of information which is most important, but at present, the most difficult to obtain. This information is the

performance of various coatings systems under real-life field conditions. In short, such an integrated program would combine the functions of coatings research, project testing, technical service, field exposure monitoring, and program administration into a Reclamation-wide coatings program.

METHODS

Panel Preparation

All of the tests were run on multiple cold-rolled steel panels which had been solvent cleaned and abrasive blasted to a near-white (SSPC-SP10) condition on both sides (Greenfield, 1994). The panels met ASTM D 609, type II specifications, except that 0.38- to 0.64 micrometer (15- to 25-μin) roughness was allowed instead of 0.38 to 0.51 micrometer (15 to 20 μin) on the flat polishing. The steel met ASTM A 109 and A 366 specifications. The panels for the QUV (QUV is a trade name of the Q-panel company) accelerated weathering test were 67 by 152 millimeters (2⅝ by 6 in); for the waterborne exterior exposure test, they were 102 by 305 millimeters (4 by 12 in), and for the remainder of the tests they were 76 by 152 millimeters (3 by 6 in). All panels were 609.6 to 965.2 micro-meters (24 to 38 mils) thick (about the thickness of a Q-panel) and were coated on both sides with the various coatings systems being tested. The 76- by 152-millimeter (3- by 6-in) panels had a 6.35-millimeter (¼-in) hole centered along one 76-millimeter (3-in) edge to make them suitable for suspension in immer-sion baths.

Coatings Application

Conventional spraying equipment was used to apply the coatings involved in the lead- and chromate-free primer investigations. The finished test panels for this investigation were prepared completely in Reclamation's laboratory. All test panels, regardless of the specific investigation and method of application, were aged in a constant temperature and humidity room (22.8 °C [73 °F], 50 percent relative humidity) for a minimum of 14 days after the final coat had been applied.

Another method of coating application was used for the high solids and 100 percent solids high performance and immersion service coatings investigations. This method was to have the suppliers of the coatings systems which were to be tested prepare and coat Reclamation supplied panels. Three objectives were accomplished by using this method:

1. Coatings which required specific (not necessarily exotic) spraying equipment as the most satisfactory method of application, and the one which would be recommended for use in the field, could be applied more satisfactorily than they could have been in-house, using in-house equipment.

2. Reclamation laboratory personnel were freed for other duties, thus saving time and project funds. A side benefit of supplier panel preparation was no in-house accumulation of hazardous material and, ultimately, hazardous waste.

3. Because coating suppliers were investing some of their own time and funds for panel preparation and coating, they were motivated to present their best available coating systems for Reclamation's applications.

The cooperation received from the coating manufacturers was uniformly excellent for all of the investigations conducted. All coatings tested were required to be commercially available or commercially available within a short period of time.

The system of panel preparation outlined was satisfactory and was chosen with regard to the resources available and the general situation at that point in time. However, the system is not claimed to be the most desirable under all situations and at all times. Driscoll (1993) has presented a very compelling case in which he states that coating application on test panels should duplicate actual application conditions. He also states that the panels should be tested in each job-site environment where the product would be used. The investigations covered in this report concern the results of laboratory testing. However, the basic purpose of the laboratory testing was to discover candidates for field testing which would have a reasonable chance for success in their intended applications.

The waterborne coating systems were applied in the laboratory using a polyfoam applicator. An advantage of this method of application was the ability to control coating thickness with a wet-film gauge and to minimize the application marks. Application properties could also be closely observed.

Coatings Systems Tested

Four basic primers were tested in the lead- and chromate-free anticorrosive primer investigation (called the RLR series). The RLR series also included a TT-P-86G, type IV red lead primer as a system control. Each of the four primers was tested by itself and with topcoats of TT-E-490E Silicone Alkyd Semigloss Enamel and TT-V-119D/TT-P320D, type 2, class B, phenolic aluminum paint. Altogether, 12 coating systems were tested. Although an immersion test was part of the testing sequence, these systems are considered nonimmersion (atmospheric exposure) coatings.

The high solids and 100 percent solids investigation (called the X series) of high performance and immersion service coatings included 12 coating systems, plus two waterborne systems. One was a waterborne epoxy immersion coating which was included in both the X series and the waterborne investigation series. The second was a standard waterborne epoxy. This coating was tested in the X series for immersion only, as a control for the first (immersion) waterborne epoxy. The second waterborne epoxy coating was also tested in the waterborne investigation.

The waterborne coatings investigation (called the W series) of replacements for solvent-borne coatings in nonimmersion (atmospheric exposure) service involved 17 coatings systems. Two of these systems were solvent-borne control coatings systems, either formerly or currently in Reclamation coatings specifications.

Throughout the remainder of this report, the three basic investigations will be referred to as the RLR, X, and W series. Tables of data will have these designations added to the table number, e.g., table 1RLR, 1X, 1W, etc. Complete rosters of all of the series tested are found in tables 1RLR, 1X, and 1W.

General Testing Guidelines

RLR series testing was based on Federal Specifications TT-P-86G, type IV, Paint, Red-Lead-Base, Ready-Mixed. A cold-water immersion test is part of these specifications (for type IV only) and accounts for the unusual inclusion of an immersion test in the investigation of atmospheric exposure coating systems.

X series testing was based on laboratory investigations performed for the CERL (Construction Engineering Research Laboratory) of the COE (Corps of Engineers) (Beitelman, 1991; 1990; 1992). The X series represents a continuation of the COE investigation by Reclamation under the WATER program.

W series testing was based on draft No. 5 of SSPC (Steel Structures Painting Council) Paint Specification No. XWBLX-90P, Latex System for Steel Surfaces, Performance Based, dated March 15, 1990. Although this specification was not, at the time the investigation was conducted, in its final form and was unofficial, the testing methods it contained were pertinent to the investigation.

Changes were made in some of the minor particulars of specific testing methods for all series where this was deemed desirable to facilitate testing procedures. A restriction was that the changes could not interfere with the collection of meaningful data.

Application Properties

For the RLR series, application properties were tested during test panel preparation. The blasted panels were coated by conventional spraying to within acceptable tolerances of predetermined dry-film thicknesses for the one coat of primer and, where applicable, the two final coats. During the preparations for the application phases of panel preparation, the coatings were checked for dispersion, consistency, and sprayability. Following application, the coatings were checked for their general drying properties and, where applicable, their recoating properties. Recoating properties were checked after an overnight drying period in the constant temperature and humidity room. In instances where overnight recoating proved to be unsatisfactory, additional panels were recoated at progressively longer periods of time until recoating properties were acceptable.

The X series testing panels were prepared by the manufacturers of the coating systems being tested. DFTs (Dry-film thicknesses) were checked for all coats and recorded for the total system. Irregularities in the surfaces of the coatings, such as orange peel, if any, were noted. The coatings manufacturers were required to supply written information on the number of coats, target DFTs, and precise identifications of the coatings applied. Further information, if desired, was obtained by contacting the coatings manufacturers.

W series application properties were tested during test panel preparation. The blasted panels were coated on both sides within acceptable tolerances of target DFTs using a polyfoam applicator. DFTs were checked for all coats and recorded for the total system. During the coatings preparation and the application phases of panel preparation, coatings were checked for dispersion, consistency, and general ease or difficulty of application. Allowances were made for the increased ease of spray relative to application by a polyfoam applicator when evaluating application characteristics. Following application, the coatings were checked for their general drying properties and recoating characteristics.

Immersion Tests

The immersion test for the RLR series was run in accordance with ASTM D 870-54 using deionized water at ambient temperature (about 22.8 °C [73 °F]). Duplicate panels were prepared for each coating and the backs and edges of the panels were properly sealed. A deviation from ASTM D 870-54 was that duplicate panels were tested with the coatings under test on one side of the panels instead of on both sides. Readings of the immersed portions of the panels were taken at 72- and either 96- or 120-hour intervals. The test sides of the panels were not scribed.

Immersion testing for the X series varied considerably from that of the RLR series. Both SW- (salt-water) and FW- (fresh-water) immersion testing were based on ASTM D 870-87. Each tank was aerated with two aquarium-style air pumps and diffusers. Both were operated at 38 ± 1 °C (100 ± 2 °F). Deionized water was used in the FW tank. Formula A of ASTM D 1141 (no heavy metals) was mixed with deionized water to form substitute ocean water for use in the SW tank. The test panels were scribed with an X on the bottom half of the "test" sides. This scribing permitted the effects of immersion to be observed on the stressed (scribed) "test" sides, as well as on the unstressed (continuous film) back sides of the panels. The test panels were immersed about three-fourths of their length. An automatic float-type controller replaced evaporated water with fresh deionized water. The panels were checked at regular intervals, usually every 1 or 2 weeks, for blistering and other film defects, during the basic 3,000-hour immersion period. Three thousand hours was chosen as the basic immersion period because experience had shown that test panels which pass this basic immersion period tend to pass appreciably longer immersion periods.

Two waterborne epoxy systems, No. 13W and 14W, were included in the above SW and FW immersion tests. System No. 13W is a new type of waterborne epoxy which is recommended for immersion services. System No. 14W is a conventional nonimmersion waterborne epoxy which was used as a control for System No. 13W. The remainder of the W series coatings systems were for atmospheric exposure only. Consequently, they were not tested for immersion.

QUV ACCELERATED WEATHERING TEST

The tests for all series were conducted in accordance with ASTM D 4587-86. A QUV unit meeting ASTM G 53 was used. The fluorescent UV/condensation apparatus was manufactured by the Q-Panel Co. (hence QUV). Continuous 4-hour condensation and 8-hour ultraviolet exposure cycles were used. The ultraviolet exposure was supplied by UVB-313 ultraviolet lamps. Operating temperatures were 60 to 65 °C (140 to 149 °F) for the ultraviolet cycles and 40 to 45 °C (104 to 113 °F) for the condensation cycles. The test panels were checked for blistering, chalking tendencies, and other film defects at regular intervals, usually every 1 or 2 weeks. All panels were scribed with an X on the bottom half of the test side. The panels were exposed for 3,000 hours total.

Tape Adhesion Test

Adhesion was tested for the RLR series using the tape adhesion test, ASTM D 3359-83, Method B. A KTA-Tator Cross-Cut Guide Kit was used to carry out the tests. The tests were run on both the immersed and nonimmersed portions of the immersion test panels. They were also run on the QUV accelerated weathering test panels after the conclusion of the QUV tests. For the W series, ASTM D 3359-90, Method B, was used. Adhesion was tested on separate test panels dedicated for the purpose.

Pulloff (Elcometer) Adhesion Test

For the X series and System No. 13W, ASTM D 4541-85, a method of pulloff adhesion testing for thicker films, was used. An elcometer adhesion tester with a range of 0 to 6,895 kilopascals (0 to 1,000 lbf/in^2) was used.

Mandrel Bend Test

ASTM D 522-88 was the basis for the mandrel bend test. Immersion-type testing panels were bent over a 25-millimeter (1-in) cylindrical mandrel and checked for the amount and severity of cracking of the coating.

Color and Color Difference Measurement

Color and color difference measurements were conducted using a Minolta CR200b colorimeter and ASTM D 2244-89, respectively. The initial colors and color difference data are in CIE 1976 CIELAB (L^*, a^*, b^*) color space. Briefly, this mapping system consists of: L^* (lightness), $+a$ (red), $-a$ (green), $+b$ (yellow), and $-b$ (blue). Total color difference is measured by ΔE^*_{ab}, which is defined as:

$$[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Both illuminants C and D 65 were used to take the color readings. Illuminant C is the more universally accepted one, illuminant D 65 measures "cooler" than illuminant C (Federation of Societies for Coatings Technology, 1978). Color differences were obtained by using a Lotus 1-2-3 Spreadsheet software computer program to make the calculation. As the values of ΔE^*_{ab} increase, the coating system becomes less color stable or stain resistant.

Chalking Evaluation

Chalking was evaluated according to ASTM D 4214-89, Method A, using pictorial standards.

Rusting Evaluation

Rusting was evaluated according to ASTM D 610-85, using pictorial standards.

Blistering Evaluation

Blistering was evaluated according to ASTM D 714-87, using pictorial standards.

Exterior Exposure Test

The exterior exposure test was conducted on the W series, only the panels were placed at a 45-degree angle on south-facing test fences located near the northwest corner of the Denver Federal Center. The panels were scribed to observe the performance of the coatings systems under damaged, as well as intact, film conditions. The panels were examined for exposure changes and damage (gloss, chalking, thermal shock, color change, etc.) after the first year and after each subsequent year of exterior exposure.

Early Rust Resistance of Primer Test

This evaluation is another test which was run on the W series only. The abrasive-blasted panels and the coatings to be applied were conditioned in a refrigerator at 10 °C (50 °F) and about 75 to 80 percent relative humidity for 30 minutes. One coat of primer was then applied to a thickness of about 36 to 46 micrometers (1.4 to 1.8 mils) DFT above the profile. The panels were returned to the refrigerator and dried for 4 hours or until the films were dry to the touch. The panels were then placed in the constant temperature and humidity room (for ambient temperature and humidity control) in a miniature, homemade, high humidity chamber, where they were covered with wet cheesecloth. The cheesecloth was draped over the panels with the edges in a pan of water so that water would wick up to keep the cheesecloth wet. The panels remained in the apparatus overnight (about 16 hours) and then were rated for rusting. The method for this test is given in SSPC designation: Paint XWBLX-90P, March 15, 1990.

Thermal Shock Test

This evaluation was the final test, which was run on the W series only. SSPC designation: Paint XWBLX-90, March 15, 1990, specifies the use of ASTM D 1211-87, an ASTM test which was developed for clear nitrocellulose lacquers applied to wood. However, this test has been found suitable for waterborne latex systems. A cycle in this test consists of:

1. One hour in an oven at 48.9 °C (120 °F).

2. One hour in a chiller at -20.6 °C (-5 °F).

3. Thirty minutes relaxation and inspection time.

The test consisted of 10 cycles, which could not be run consecutively because of time constraints. The panels had to be stored in the constant temperature and humidity room overnight between clusters of cycles. Four working days were required to complete the 10 cycles. After each cycle, the panels were checked to determine whether the coating had failed.

RESULTS

Detailed Results

Detailed results of the testing conducted on all series are contained in the tables in appendix A.

Interpretation of Results

As important as quantitative numbers are, they cannot tell the whole story. Good examples are adhesion tests. The numerical ratings say nothing about the planes of failure. Written comments are required to describe these planes (substrate, intercoat, etc.). Also, on mandrel tests, epoxies, which are relatively brittle coatings, may crack, whereas polyurethanes, which are relatively flexible coatings, usually will not. If an epoxy did not crack or a polyurethane did crack, those results would have significance. The most clear-cut pass/fail judgments existed for the test sides of the panels which were immersion tested. Definite blistering (except on the edges) was considered failure.

Having accepted the fact that test results need interpretation, the related questions that naturally arise are:

> "What factors must be considered and what coatings properties, as established through the testing process, must be compared during the interpretation?"

Factors considered for these investigations were:

1. General exposure conditions.

    a. Water immersion and/or buried service.

    b. Water immersion and atmospheric exposure service on the same structure (e.g., radial gates).

    c. Interior or exterior atmospheric exposure service.

    d. Importance of appearance as well as corrosion protection in exterior exposure service (e.g., epoxy-coated radial gates exposed to public view versus those that are in remote locations where the predicted chalking would not be a serious detriment).

2. Special exposure conditions.

    a. Exposure to severe impact and/or abrasion.

    b. Contact with chemicals (including salt water).

    c. Contact with drinking water.

    d. Intermittently wet areas (principally from condensation); items which are constantly wet are treated as if they were in water immersion service.

    e. Areas where abrasive blasting is undesirable or cannot be used (confined spaces, deck machinery, etc.).

Coatings properties compared, as established through the testing process, were:

1. Limitations on application conditions.

    a. Is shop and field application feasible, or shop application only?

    b. Recoating and curing times (connected with total down times.)

    c. Special properties (ability to be applied over damp surfaces, etc.)

    d. Application equipment required.

    e. Degree of skill required for satisfactory application.

2. Physical properties comparisons.

    a. Immersion resistance and accelerated weathering resistance (for coatings systems which will experience both immersion and atmospheric exposure.)

    b. Adhesion and mandrel bend. - What laboratory testing values correspond to satisfactory field performance?

    c. Accelerated weathering versus test fence weathering for atmospheric exposure coatings.

    d. Color shift and gloss retention for atmospheric exposure coatings.

e. Salt-water immersion resistance versus fresh-water immersion resistance.

f. VOC content versus performance.

Many factors have to be weighed against one another when interpreting testing results.

DISCUSSION

1. TT-P-86G, type IV, Red Lead Primer was the only primer tested in the RLR series which had a long history of satisfactory service on Reclamation projects. This coating was often topcoated with TT-V-119D/TT-P-320D, type II, class B, phenolic aluminum paint. This primer-topcoat combination has given almost 40 years of acceptable corrosion prevention service in various atmospheric exposure applications. However, on the ASTM D 3359-83, method B, (cross-batch adhesion) test, this coating system had the lowest rating possible, 0B, the lowest of any of the comparable aluminum topcoated systems tested. Failure was at the substrate. Also, the red lead primer itself had the lowest adhesion rating of any of the primers tested, although it maintained its adhesion better after immersion than one other primer. These results, once again, indicate the caution required when attempting to extrapolate laboratory numbers to real-life performance.

The three lead- and chromate-free primers all performed relatively well. One apparent drawback was the tendency toward intercoat blistering during the topcoated primer immersion tests. Further investigations revealed that salts had been deposited at the primer/topcoat interfaces before the topcoats were applied. Only those panels coated with the red lead primer and one coated with System No. 4-3 showed no blistering. This result pointed out one of the strengths of the red lead primer, assuming no coating compatibility problems were present. Red lead apparently has more of a neutralizing effect on contaminating salts than the lead- and chromate-free anticorrosive pigments (Funke et al., 1986; Ruvolo-Filho and daCosta, 1993).

Lead- and chromate-free primers are now the standard primers being used on Reclamation field projects. The traditional lead and chromate containing primers have been eliminated from Reclamation guide specifications for at least 6 years. However, some old construction specifications which contain requirements for chromate-containing TT-P-636D Alkyd Oxide-Chromate Primer (now a cancelled specification) still surface occassionally. Also, in one instance equipment fabricated overseas arrived primed with red lead paint. The primer had carbonated during the journey. This tendency for the surface to change from lead oxide (orange) to lead carbonate (white) during exposure was observed during the QUV accelerated weathering test. System No. 4, CALTRANS (California Department of Transportation) primer exhibited heavy chalking in the same test. Systems No. 2 and 3 were based on phenolated alkyds and did not exhibit heavy chalking. Consequently, Systems No. 2 and 3 were the only ones which would be suitable for "shop coats," which were to be topcoated at a later date.

Field experience with the lead- and chromate-free primers tested, as well as with a number of "or equals," has been satisfactory so far in their intended atmospheric exposure service. The immersion tests were for information only and were required by the TT-P-86G, type IV, specifications. No blistering or loss of intercoat adhesion has been observed on the field applications of the lead- and chromate-free primers. Only time will tell whether or not the long term exposure performance of these primers will equal that of TT-P-86G, type IV, Red Lead Primer.

2. The X series of coatings systems were more varied in basic composition and curing mechanisms than either the RLR or W coatings systems. Overall, the X series investigations were continuations of those sponsored by the COE and reported on in a REMR (Repair, Evaluation, Maintenance,

and Rehabilitation) technical report (Beitelman, 1992). Program management was provided by the CERL at Champaign, IL. This report and the REMR report contain the results of investigations conducted on 36 high solids and 100 percent solids low VOC coatings systems. The X series alone consisted of 12 coatings systems.

Only System No. 12X indicated problems with application. The problems may have been caused by the apparent method and technique of application rather than the coating system itself. Nevertheless, the application defects observed would dictate caution in giving unqualified approval to this system at this time.

Actual DFTs of most systems were acceptably close to the target DFTs. However, Systems No. 9X and 11X were above, and Systems No. 4X, 5X, and 12X were below, their target DFTs. These differences in the DFTs versus the target DFTs, although larger than desirable, apparently did not materially affect the test results. The W after 13W indicates that it is a waterborne system. This system is, however, very much a part of the X series as well, because it is suitable for high performance and immersion applications. In this sense, it is a "unique" Reclamation coating system as of the time this report was written.

The X coatings systems performed as expected in the QUV accelerated weathering test with the exceptions of Systems No. 4X, 8X, and 9X. Systems No. 8X and 9X were topcoated with aliphatic polyurethanes, which have the reputation of being chalk resistant and color stable. System No. 12X, an epoxy, achieved the same chalk rating, 6, as did Systems No. 8X and 9X. Illuminant C ΔE^*_{ab} color shifts of Systems No. 8X and 9X were 5.03 (low) and 12.65 (high), respectively. System No. 4X was unlike any other air-type coating which Reclamation had tested. Its chalk rating of eight was the least of any of the X series systems. Reclamation practice has been and, as of the time this report was written, still is, to not use tar-containing coatings in direct sunlight exposure conditions. Systems No. 4X and 10X had the same aromatic refined tar moisture cure polyurethane topcoat. Consequently, only System No. 4X was tested in the QUV accelerated weathering test. In addition to its surprisingly good chalk rating, this system had a low illuminant C ΔE^*_{ab} color shift of 4.20, the lowest of any of the systems tested. The manufacturer of Systems No. 4X and 10X was consulted about this result and replied that these systems were still in good condition after several years exposure to direct sunlight on steel bulkheads. Reclamation field trials of one or both of these coatings systems in direct sunlight, if successful, could change the absolute ban on the exposure of tar-containing coatings to direct sunlight to a selective one.

The lamps used in the QUV cabinet were UVB-313 ultraviolet lamps. The wavelength distribution on this type of lamp is especially hard on polyurethanes. Consequently, the polyurethane coatings systems would be expected to perform relatively better in actual exterior exposure than they did in the QUV accelerated weathering tests.

The epoxies exhibited their usual and expected heavy chalking and associated color shifts. System No. 12X was not monitored for color change because the topcoat exhibited floating, a defect which causes uneven color on the test panels. This system had the best chalk rating, 6, of any of the epoxies tested, however. When coating hydraulic structures where appearance above the waterline is not important, the current practice is to use the epoxy without a weathering topcoat. Weathering aliphatic polyurethane topcoats, which are compatible with their epoxy base coats and which have reasonable resistance to water immersion, are available from many epoxy manufacturers for use where appearance is important. These topcoats are for use under water immersion conditions only when they are used as topcoats for epoxy basecoats and are not immersion resistant coatings by themselves.

Investigation of the influence of test panel thickness on the values obtained in the elcometer pulloff adhesion test were part of the COE CERL-sponsored research program referred to previously in this report. Thicker panels gave appreciably higher readings by a factor of at least 2+. Subsequent investigations have produced very similar results. The thick panels were 3,175 micrometers (125 mils) versus 610 to 965 micrometers (24 to 38 mils) for the regular or "thin" test panels. Consequently, the X series and 13W coatings tested should have adequate adhesion for all practical purposes when used in the field.

Adhesion of the coatings systems was satisfactory. Systems No. 1X and 2X, both 100 percent coatings, were the only ones which released 100 percent to the substrate. Although overall adhesion of the two systems (1,034 to 1,379 kilopascals [150 to 200 lbf/in^2]) was adequate, the 100-percent removal to the substrate indicates that wetting of the substrate was not as complete as with the high solids systems. This result is a known problem with some 100 percent solids coatings and is sometimes compensated for by heating the coating to provide lower application viscosities. The highest adhesion values (3,448 kilopascals [500 lbf/in^2]) were achieved by System No. 3X, and the lowest were registered by System No. 4X (738 kilopascals [107 lbf/in^2]). Adhesion to the substrate was higher than intercoat and intracoat adhesion for Systems No. 5X, 6X, 7X, and 8X. The waterborne epoxy system, System No.13W, showed satisfactory adhesion (1,379 kilopascals [200 lbf/in^2]); 90 percent of the disbondment occurred at the substrate and 10 percent occurred between coats. Apparently, System No. 13W, a waterborne epoxy, shared the same incomplete wetting of the substrate as did Systems No. 1X and 2X. System No. 12X, however, which is another 100 percent solids epoxy coating, showed only 2 percent disbondment at the substrate. This result indicates that not all 100 percent solids epoxies fail to achieve near 100 percent wetting of the substrate under similar conditions. For the moisture cure polyurethanes, the adhesion values ranged from 738 to 1,103 kilopascals (107 to 160 lbf/in^2; 97 to 100 percent of the failure was intercoat or intracoat.

The mandrel bend test measures the performance of a coating system under conditions of flexural stress and elongation more severe than the system is expected to undergo under actual exposure conditions. System No. 1X, an elastomeric polyurethane, and System No. 13W, a waterborne epoxy, showed no cracking. The other X series coatings systems, all epoxies or moisture-cure polyurethanes, except for one epoxy with a two-package acrylic aliphatic polyurethane topcoat, showed cracking to some extent. Only one system, System No. 2X, showed loss of adhesion at the substrate. This system was a 100 percent solids epoxy coating and might have achieved better adhesion if it had been heated to lower its viscosity and promote better wetting of the surface. System No. 13W, the waterborne epoxy, was one of the few epoxy systems which have been tested to exhibit no cracking at all.

The immersion tests are the "heart" of the testing process for immersion coatings. Although they are not infallible predictors of long term performance in the field (the search for accelerated tests which would be good predictors of actual coatings performance, continues), the salt-water and fresh-water immersion tests have proved to be among the more significant and reliable accelerated tests. Also, they are "real-life" or performance type tests. Systems No. 4X, 5X, 6X, 10X, and 13W passed the initial 3,000-hour immersion tests in both salt water and fresh water. "Pass" or "fail" is determined by the ability of a coatings system to withstand 3,000 hours of immersion in fresh (deionized) water without manifesting blistering or other immersion induced defects. Experience has shown that if a coating passes 3,000 hours in either salt-water or fresh-water immersion, or both, it will maintain its good condition much longer in the same immersion medium(s). An example is shown by the data in table 4X. Times to 100 percent rusting in the scribe were recorded. As table 4X shows, 100 percent rusting in the scribe often took place much more rapidly in fresh-water immersion than in salt-water immersion. Possible causes are the greater solubility of oxygen in deionized water and ionic concentration gradient effects. Blistering occurred more frequently in salt-water immersion. Coatings such as System No. 4X, 5X, 6X, 11X, 12X, and 13W, which did not exhibit any osmotic blistering in salt-water immersion, are probably more resistant to the diffusion of ions through the film. It is interesting to note that Systems No. 1X and 3X, which were the only systems to have blistering on the backs of one panel in the salt-water immersion test, were still in good unblistered condition in the fresh-water immersion test after 16,000 and 17,000+ hours, respectively. Systems No. 2X, 7X, 8X, 9X, and 10X also passed 3,000 hours in fresh-water immersion and, although their test (scribed) sides blistered in the salt-water immersion test, no blistering occurred on the backs of the panels.

Some reversals occurred in the results of these tests which had not been witnessed before. Systems No. 11X and 12X both passed the salt-water immersion test, but both panels of System No. 11X and one panel of System No. 12X failed the fresh-water immersion test. Neither of these systems exhibited any blistering on the backs (unscribed sides) of the test panels. Previously, no panels which had passed the salt-water immersion test on the test (scribed) side of the panels had ever failed the fresh-water immersion test. A coatings system was considered acceptable for field testing, or field use, if it passed the fresh-water immersion test, because Reclamation exposure conditions are more akin to "fresh" than "salt" (synthetic sea) water conditions. About one-third of the total number of the immersion coatings systems tested to date which have passed the fresh-water immersion test have also passed the salt-water immersion test. Consequently, the salt-water immersion test is considered a tougher test of a coatings system's ability to withstand immersion under a variety of conditions. In short, passing the salt-water as well as the fresh-water immersion test is considered to be a desirable attribute for an immersion coatings system used under conditions typical of the Reclamation area of operation.

These anomalies created a problem in deciding whether the criteria for acceptance should be modified from "passing the fresh-water test" to passing the statistically more difficult salt-water test *or* the fresh-water immersion test. When one test panel passes a test and the other one does not, it must be presumed that the panels were different in some unknown way. A possible, but not certain, cause of such inconsistent behavior is the introduction of contaminated spots on the failed test panels during the fabrication, surface preparation, or coatings application phases of those panels. It is interesting to note that the failed immersion panels were in excellent nonblistered condition on their back (unscribed) sides. This characteristic is not unusual, so film stresses from the scribing process are a possible, although not definite, cause of the susceptibility to blistering. The hours to initial blistering, which appear on the tables, are the testing hours which have expired as of the time the panels were "read." Consequently, panel No. 2 of System No. 10X was considered "passing" in the salt-water immersion test, even though blistering occurred at a nominal 3,080 hours. The exact time the blister appeared between about 2,912 and 3,080 hours is unknown, but the benefit of the doubt is given to the test panel. Systems No. 11X and 12X were unique in that they both passed the salt-water immersion test and both had one or both panels fail in the fresh-water immersion test. Blisters first appeared on both panels of System No. 11X at 2,004 hours and one panel of System No. 12X at 2,880 hours. All panels of both systems had no blistering on their back (unscribed) sides. Because both systems passed the more difficult salt-water immersion test, and one panel of System No. 12X passed the fresh-water immersion test, both systems were considered as passing overall. The lack of blistering or other defects on the backs of the panels where the coating was continuous, without the stress of a deliberate "insult," was another factor in the decision, as was the fact that System No. 11X is suitable for use with cathodic protection. System No. 9X, which passed the fresh-water immersion test, and one panel of which passed the salt-water immersion test, has a moisture cure polyurethane zinc-rich primer and would be used where cathodic protection was not in place or its installation was not contemplated.

Another less important anomaly occurred with this set of test panels in the immersion tests. The number of hours until 100 percent rusting took place in the scribe lines has consistently been less than the total hours (3,000+) of immersion. In this testing sequence, Systems No. 10X and 11X (salt-water immersion) and System No. 4X (one panel in fresh-water immersion) had less than 100 percent rusting in the scribe lines. At the completion of the tests, as has been mentioned, rusting in the scribe lines usually proceeds more quickly in fresh-water immersion than in salt-water immersion. Three exceptions occurred in this testing sequence, Systems No. 4X, (one panel), 9X (two panels), and 12X. System No. 12X had a low of 18 hours before 100 percent rusting in the scribe lines was recorded in salt-water immersion, versus 1,022 hours in fresh-water immersion.

Contamination of the immersion baths has to be considered as a possible explanation of most of these anomalies because construction work and a change of location were involved during the testing process. No hard evidence exists that this explanation is so, however.

The extent and direction of color change in the immersed portion of the test panels is an indirect measure of stain resistance. Color shifts are predominantly in the yellow and red directions with some lightening or darkening. Yellow and red combine to form brown, the color of rust. The panels are wiped with a tissue before the previously immersed panels are checked for color. The wiping process is to remove loose rust which has settled on the bottom test area from the rust in the scribe lines. What remains is in the form of a stain. Systems No. 2X and 3X showed the smallest degree of color change in both salt-water and fresh-water immersion. System No. 13W showed a small color change in salt-water immersion, but a relatively large one in fresh-water immersion. A possible reason is increased rusting along the scribe in fresh-water immersion. Surface characteristics affect stain resistance. Rougher or more porous surfaces are more likely to stain than smooth, continuous ones.

3. Application properties were satisfactory for all of the coatings in the W series. Although to save time and clean-up problems, the testing panels were prepared using a polyfoam brush instead of the intended spraying method, good information was obtained. Actual DFTs were acceptably close to the target DFTs, except for Systems No. 7W, 8W, 11W, 14W, and 17W. No evidence exists to show that the lower total DFTs of those coatings systems affected the outcome of the atmospheric exposure testing which was done. Samples of System No. 15W, which were shipped during cold weather, exhibited cracking during the drying process, even though no application difficulties occurred. A sample shipped in warm weather did not exhibit cracking.

The QUV accelerated weathering test included two control coatings systems, Systems No. 1W and 2W. These systems were currently specified (1W) or prospectively specified (2W) alkyd systems for nonimmersion applications. Each system had the same TT-E-490E silicone-alkyd semigloss enamel topcoat. The difference was in the primers used. System No. 1W used the traditional (now cancelled and not appearing in Reclamation guide specifications) TT-P-636D alkyd oxide-chromate primer. System No. 2W used the relatively new lower VOC lead- and chromate-free primer, TT-P-664D. For information purposes, a third system, System No. 6W, used a latex metal primer (no longer commercially available) with the TT-E-490E topcoat. Percent gloss retention of the TT-E-490E topcoat was not significantly different for the three systems after 3,000 hours of exposure.

However, the chalk rating of System No. 2W averaged only 5, whereas the other two systems averaged 8.

Only one system (10W) with an acrylic emulsion topcoat had an average chalk rating of 10 (no chalking) in the QUV accelerated weathering test. All of the waterborne epoxy systems, as expected, exhibited relatively heavy chalking. The percent gloss retention figures which appear in tables 3W, 5W, and 8W must be correlated with the initial gloss figures because some coatings systems had very low initial gloss readings. Percent gloss retention for some of the higher gloss acrylics, Systems No. 5W, 9W, and 10W, were at roughly the same level as the silicone alkyd semigloss controls; System No. 10W was a bit above them, and Systems No. 5W and 9W were a bit below. Color change (ΔE^*_{ab}) for all of the acrylics emulsions was low; System No. 11W was the highest. System No. 11W had illuminants C and D65 readings of 4.35 and 4.55, respectively. Color differences for the epoxies (illuminant C) ranged from 3.39 (System No. 8W) to 12.92 (System No. 13W). Systems No. 11W and 13W were the only ones with topcoats which were tinted (dark gray and green, respectively). Consequently, they would be expected to show greater shifts in color than would the white topcoats. Systems No. 1W and 2W, the alkyd controls, and System No. 6W with an alkyd topcoat had color shifts in the same ranges as the acrylic emulsions. System No. 13W was unique in that it was tested as both an immersion and an atmospheric exposure coating system. Consequently, it appears in both the X and W series tables. For comparison, System No. 14W was placed in the SW and FW immersion tests as a control. System No. 14W is not an immersion coating system, so its failure in the immersion tests was expected and was not considered a detriment when evaluating it for its intended applications. As expected, the immersion tests confirmed the great difference between the two waterborne epoxy coating systems. System No. 13W passed both immersion tests easily, something not all solvent-borne high performance coatings systems have been able to do. The development of waterborne epoxies which can be used in some of the same exposure as solvent-borne epoxies is an important achievement and is a welcome addition to the HS&E compliant arsenal.

Exterior exposure testing is, obviously, more definitive than accelerated weathering testing in predicting field performance. This testing is, however, subject to limitations. For example, exposure conditions are different in Arizona or Southern California than they are in Idaho or Montana. Fortunately, the weather at the Denver Federal Center is similar to at least some of the weather features typical of the 17 western States, which constitute Reclamation's area of operation. The Denver Federal Center has strong sun, temperature cycling on a daily basis, hot and cold weather, and a relatively dry overall climate. QUV accelerated weathering test results are compared with the exterior exposure test results in tables 5W, 6W, and 8W. Both 1- and 2-year exterior exposure period results are given for Systems No. 1W to 13W.

EE results did not become truly meaningful until the completion of 2 years exposure time. The silicone alkyd (TT-E-490E) topcoated systems (control 1W, control 2W, and 6W) all had 2-year chalk ratings of 8 and percent gloss retentions of 18.1, 23.5, and 24.9. The 3,000-hour QUV exposure values for the same systems and tests were 8, 5, and 8; and 26.3, 31.4, and 35.6. Illuminant C ΔE^*_{ab} color differences (EE) were 8.26, 7.95, and 9.08; and QUV were 0.47, 0.62, and 0.95. For the TT-E-490E silicone alkyd topcoated systems, 2 years of EE was more severe than 3,000 hours of QUV exposure for loss of gloss and color change, but less severe for chalking.

The acrylic emulsion systems with "gloss" or semigloss enamel topcoats (the system with the highest initial 60° reflectance angle as measured from the vertical. The "gloss" readings averaged 80.6) were Systems No. 3W, 5W, 9W to 11W, and 15W to 17W. The topcoat of System No. 11W was dark gray in color, the others were whites. These systems had 2-year EE respective chalk ratings of 10, 9, 10, 10, 8, 9.5, 10, and 8; and percent gloss retentions of 58.5, 72.3, 65.6, 42.4, 17.1, 67.7, 92.1, and 17.6. Corresponding QUV values were 8, 8, 9, 10, 8, 5, 9, and 8; and 19.5, 23.5, 23.8, 35.9, 15.3, 19.8, 25.9, and 9.3. Illuminant C color differences (2-year EE) were 7.66, 7.75, 7.79, 8.50, 4.96, 7.27, 7.96, and 6.48; and QUV differences were 0.50, 0.42, 0.47, 0.68, 4.35, 0.91, 0.70, and 1.49. Unlike the TT-E-490E silicone alkyd topcoated systems, EE was less severe than 3,000 hours of QUV exposure for chalking and loss of gloss for the acrylic emulsion enamel coatings systems. Color change after 2 years of EE was appreciably higher than after 3,000 hours of QUV exposure for both the silicone alkyd and acrylic emulsion enamel coatings systems.

Another group of acrylic emulsion coatings systems were represented by Systems No. 4W and 12W. They had the same low sheen topcoat with initial ?60 °? gloss readings of 4.0 to 6.0. Because they had low initial glosses and were subject to "polishing" actions by wind and rain, they had 2-year EE percent gloss retentions of 92.5 and 97.9, respectively. At the end of 1 year of exposure, they had percent gloss retentions of well over 100. Even after 3,000 hours of QUV exposure, their percentages were a high 54.5 and 60.0, respectively. EE chalk ratings were 10 and 9, respectively, and 3,000-hour QUV chalk ratings were six for each. Illuminant C color differences were 7.53 and 7.66, respectively, and 3,000-hour QUV color differences were 0.58 and 0.52.

The same overall differences between 2 years of EE and 3,000 hours of QUV exposure were noted for the low sheen systems as were noted for the acrylic "gloss" and semigloss topcoats. However, less loss of gloss took place with the low sheen systems. In other words, they tended to retain more of their initial gloss even though that gloss was low than did the higher gloss systems. The 60° gloss readings of TT-E-490E silicone alkyd control topcoats were only slightly higher than those of the low sheen acrylic emulsion topcoats after 2 years of EE.

System No. 17W, which is a gloss acrylic emulsion coating, exhibited anomalous behavior. Not only was its gloss retention of 17.6 percent after 2 years of EE lower than that of System No. 16W, its semigloss counterpart, it exceeded only the gloss retention of the waterborne epoxies and one dark gray acrylic emulsion topcoat. Its chalk rating of 8 was also lower than that of its semigloss counterpart, which had a chalk rating of 10. Its performance after 2 years of EE was similar to the dark gray acrylic emulsion topcoat (System No. 11W) and the silicone alkyd semigloss control topcoats. In only one area, ΔE^*_{ab} color difference, did both Systems No. 11W and 17W do better than the other coatings tested. Their ΔE^*_{ab} color differences after 2 years of EE were the lowest at 4.96 and 6.48, respectively.

Systems No. 7W, 8W, 13W, and 14W are waterborne epoxy systems. These systems would be used in special situations where their increased resistance to chemicals and corrosion and their generally good adhesion would be required. In exterior exposures where appearance was important, a compatible weathering topcoat, such as an aliphatic polyurethane, would be necessary. Most of their applications would be expected to be under interior, predominantly atmospheric, exposure conditions. System No. 13W is unique in the W series in that it is both an immersion and atmospheric exposure coating. As such, it appears in both the X and W series and tests. Unlike the other W series coatings, System No. 13W could be used in interior applications where heavy and/or steady condensation was present. System No. 13W has a compatible aliphatic polyurethane topcoat available which is suitable for both immersion and nonimmersion conditions. As would be expected, chalk ratings and percent gloss retention were lower than for the other types of coatings systems tested. Systems No. 7W and 8W had 2-year EE chalk ratings of 7.5 and 7.0, respectively, and respective percent gloss retentions of 10.1 and 9.8. After 3,000 hours of QUV exposure, their respective chalk ratings were both four and their respective percent gloss retentions were 16.7 and 13.0. System No. 13W had a reversal of its chalk rating in EE. Its 1-year chalk rating of 6 had increased to 7 by the 2-year inspection date. EE (2 years) percent gloss retention was 11.3. After 3,000 hours in the QUV accelerated weathering test, System No. 13W had a chalk rating of 2 and a percent gloss retention of 13.3. System No. 14W had an EE chalk rating of 10 and a percent gloss retention of 11.1 after 2 years of exposure. The 3,000-hour QUV test figures were 6 and 9.1, respectively. EE 2-year illuminant C color changes for Systems No. 7W, 8W, and 13W were 6.96, 6.90, and 11.34, respectively. The System No. 13W topcoat was green; the other topcoats were white. The 3,000-hour illuminant C QUV figures were 3.91, 3.39, and 12.92. The 2-year EE illuminant C figure for System No. 14W was 6.88 and the QUV illuminant C figure was 3.74. Unlike the other systems tested, gloss retention for the 3,000-hour QUV test was better (higher) than for the 2-year EE test. With the exception of System No. 14W, color changes were also better (lower) for the 3,000-hour QUV test than for the 2-year EE test. Chalking of the topcoats was noticeably more severe for the 3,000-hour QUV test than for the 1- or 2-year EE tests. This latter result in a milder form was also exhibited by the other types of coatings systems tested.

Adhesion was tested using the cross-hatch adhesion test for all coatings systems except System No. 13W. System No. 13W was tested using the elcometer pulloff adhesion test, the same test used for the X series. Systems No. 3W to 5W, 7W to 8W, 10W, and 14W to 17W showed perfect adhesion and no disbonding of the coating, either intercoat or to the substrate. System No. 10W had an adhesion promoting agent mixed with the intermediate coat. System No. 11W is the same system (waterborne inorganic zinc primer, acrylic emulsion topcoat with adhesion promoter) but of a gray color instead of white. Unlike System No. 10W, limited intercoat separation. Limited intercoat separation also occurred with System No. 1W, one of the solvent-borne controls, and more extensive intercoat separation occurred with System No. 2W, the other solvent-borne control. System No. 6W, which had a solvent-borne topcoat over an acrylic metal primer, also showed some intercoat separation, as did System No. 9W, an acrylic emulsion from one manufacturer over a waterborne inorganic zinc primer from another manufacturer. The poorest adhesion, with most of the removal to the substrate, was shown by System No. 12W, a waterborne inorganic zinc primer with another manufacturer's acrylic primer/finish topcoat. System No. 13W, the waterborne epoxy for immersion, was tested using the elcometer pulloff adhesion tester. This system registered a 1,379-kilopascal (200-lbf/in^2) pulloff value, a value which would have been higher on a thicker panel. This value is adequate for practical purposes, and adhesion along the scribe after 1 year of exterior exposure was excellent. Release at failure was to the substrate, indicating good intercoat adhesion in the elcometer pulloff test.

Although the priming coats of a coatings system are a vital component of those systems and affect overall performance, the tests commented upon to this point, with the exception of the adhesion tests, concerned primarily the topcoats. The early rusting test concerned only the priming coats. This test measures the ability of a primer to resist early, or "flash," rusting under cool and damp ambient and surface conditions.

The primers which passed the early rust resistance test were Systems No. 4W, 9W, and 14W to 16W. System No. 4W was an acrylic emulsion primer/finish coating which blistered (acceptable for this test) but did not rust. System No. 9W was a waterborne inorganic zinc primer which did not either rust or blister. Although System No. 9W was applied thicker than the other coatings because of its heavy consistency, the sacrificial nature of the zinc prevented rusting. This early rust resistance test is a particularly severe one. Failure to pass does not necessarily disqualify a coating from field use, because under more normal application conditions, no early rusting was observed with any of the coatings in the testing series. However, failure does indicate the need to be especially cautious when cool, damp conditions are present during the application of the waterborne coatings which did not pass this test. When in doubt, a system which has passed the test should be chosen.

Results from the thermal shock test were uniformly excellent. All of the coatings systems received a "10," no defects, after both 1 and 2 years of EE. Although the thermal shock test is an accelerated test, it is a "real world" type of test. The type of thermal cycling the panels receive, although extreme, is similar to the "warm days, cool nights" type of cycling prevalent in many areas where Reclamation operates.

The mandrel bend test measures the performance of a coatings system under conditions of flexural stress and elongation that are relatively more severe than the thermal shock test. Of the waterborne coatings systems, only System No. 14W, the architectural waterborne epoxy, showed cracking. Slight cracks occurred along the bend area. System No. 2W (TT-P-664D primer/TT-E-490E silicone-alkyd semigloss enamel topcoat), one of the solvent-borne coating system controls, cracked when the panel was bent over the 25-millimeter (1-in) cylindrical mandrel. Both systems passed the thermal shock test, however.

Color difference measurements are not significant below a ΔE^*_{ab} of 0.50, the just noticeable difference in color perceived by the human eye. Two illuminants were used: illuminants C and D65. Although illuminant D65 is supposed to be more representative of the colors in natural sunlight, illuminant C is the older and more widely established illuminant. Consequently, only illuminant C values appear in table 8W. With the exception of System No. 13W, EE color differences (ΔE^*_{ab}) were significantly greater than those recorded for the 3,000-hour QUV accelerated weathering tests. Test panels exposed in the QUV testing apparatus were subjected to the UV wavelengths generated by the UVB-313 ultraviolet lamps and water condensation. Those exposed on the Denver Federal Center test fences were subjected to all of the UV wavelengths of natural sunlight, wind-driven particulates, rain striking them from different angles and with different degrees of force, and airborne contaminants. Occasionally, some panels were even blown off the fence by gale-force winds. The test fences have since been modified in an attempt to prevent a recurrence. Under such conditions, it is not surprising that larger color changes were measured for the EE tests. Some of the natural forces that the EE test panels were subjected to can be beneficial in reducing loss of gloss and improving chalk ratings. A driving rain will wash away an appreciable amount of chalk, thereby temporarily restoring better chalk ratings and slowing down the loss of gloss.

One of the "eternal questions" in the coatings industry is, "How many hours or months of QUV accelerated weathering test exposure equal a longer period of exposure under actual EE conditions?" This question can be answered only in the most general terms, and then only for a specific set of QUV cycles, lamps, and exposure times, coupled with a specific EE location, and at least average general weather conditions during the period of exposure at that location. For the W series investigation, overall *rough* "equivalents" of years of EE exposure to 3,000 hours in the QUV accelerated weathering test are summarized on the following page.

As the summary of the data (including notes) indicates, variations exist between generic systems, properties, and even between members of the same generic systems for the same property. The W series investigation did not generate any definite answers to the "eternal question."

SUMMARY

The effort to find satisfactory candidate alternative coatings systems to replace old standard types of coatings systems, which were about to be eliminated for HS&E reasons, was successful. Many of the candidate coatings

Generic type (topcoats)	Chalk rating	Percent gloss retention	[4]Color difference
Solvent-borne silicone alkyd controls	2+	2-	[1]0.25-
Low gloss acrylics	2+	2+	[1]0.17-
"Gloss" and "semigloss" acrylics	2+	2+	[1,2]0.17-
Waterborne epoxies	2+	2-	[3]2.00-

[1] Based on 1-year EE values. One year EE values were higher than 3,000-hour QUV values.
[2] The 3000-hour QUV figure was higher than the 1-year EE reading for one system, No. 11W. On the basis of 1 year of EE, the figure for this system would be 4+, but after 2 years of EE, 2-.
[3] Two-year EE readings were compared with 1-year EE readings and with 3000-hour QUV readings.
[4] Illuminant C ΔE^*_{ab}.

systems are being field tested by Reclamation and/or other public and private organizations with features which require the same types of protective coatings systems. Several of the all-around most desirable candidates are in the most recent Reclamation coatings guide specifications (Reclamation, 1994).

Several generalizations can be made regarding the "old" versus the "new" coatings systems. Like all generalizations, they will be subject toexceptions, either in the present or as improved versions of the "new" coatings systems are developed in the future.

The most obvious differences between the "new" and the "old" coatings systems are the comparative difficulties of application, including the degrees of surface preparation required. The "old" coatings systems were more forgiving. Red lead primers, for example, could be applied using brush or basic spraying equipment by "painters." Surface cleanliness was less critical because of red lead's ability to inactivate limited amounts of corrosive salt-type contaminants (Federation of Societies for Coatings Technology, 1978). The solvent-borne lead- and chromate-free anticorrosive primers perform well, but they require a higher standard of surface cleanliness. They do a good job of preventing corrosion when applied to surfaces with very low levels of or no salt-type contaminants (Funke et al., 1986). Waterborne coatings' vulnerability to residual oil or grease is known. After they have been removed, SSPC-SP6 Commercial Blast Cleaning is required. Some of the lead- and chromate-free solvent-borne primers also require SSPC-SP6 grade blast cleaning or equivalent degrees of surface preparation. The appropriate grades for specific features are given in the Reclamation guide specifications. Although waterborne primers require a little more technique in application, they are not appreciably more difficult to apply than conventional solvent-borne primers. The lead- and chromate-free primers, particularly those with high solids, such as TT-P-664D (one of the solvent-borne control primers in the W series), require more than just basic spraying equipment. On the brighter side, the solvent-borne lead- and chromate-free primers, on the basis of laboratory and short-term field testing, are viable alternatives to the old TT-P-86G, type IV, red lead primer. On the basis of laboratory testing alone, at this point, several waterborne primers or primer/topcoats are viable alternatives to solvent-borne primers, although not necessarily in all locations. Not too many years ago, a waterborne epoxy which would pass 3,000+ hours in both salt-water and fresh-water immersion tests would have seemed like a pipe dream. However, System No. 13W did just that. Improvements are continuing to be made in waterborne primers, traditionally the "weak link" in waterborne coatings systems for metal. To date, the acrylic emulsion topcoats have outperformed the control TT-E-490E silicone-alkyd topcoats overall. Similar results have been reported by others. The good performance of the acrylic emulsion coatings has been confirmed, but these coatings should not be applied when the temperature is below 10 °C (50 °F) if their performance potential is to be realized (Baker and Chasan, 1994). A switch to waterborne coatings, where they can be satisfactorily used, offers one of the principal means of reducing VOC emissions and regulatory problems. VOC reduction, as important as it is, is not the only factor to be considered in formulating and choosing coatings systems. Coatings systems must be free of all forbidden raw materials, not just lead and chromates. This requirement applies equally to solvent-borne, waterborne, and 100 percent solids coatings systems. Considering the constantly increasing numbers of obstacles coating technologists have faced, the results of the investigations chronicled in this report indicate that these technologists deserve an "A," and not just for effort.

A dominant proportion of the coatings systems used on hydraulic structures have been, and in the immediate future will be, solvent-borne (examples: vinyls, epoxies, polyurethanes) or 100 percent types (examples: coal-tar enamel, 100 percent solids epoxies). The traditional VR-3 and VR-6 vinyls and coal-tar enamel are hard acts to follow. The vinyls can be used both above and below the waterline. They have good flexible protective qualities at and below the waterline and good aesthetic qualities above it. Unfortunately, they are above any current or proposed limits on VOC. Some efforts have been made by coating manufacturers to develop high solids vinyls. So far, these efforts have resulted in high solids "vinyl-modified" types of coatings rather than in high solids "true" vinyl types, which have the properties of existing vinyl systems. All coal-tar containing coatings systems have come under cycles of attack followed by calm in the last decade or so. Coal-tar enamel, because it is applied in a molten (and hazardous) state during which it gives off potentially dangerous vapors, has experienced severe OSHA restrictions governing its conditions of application. This restriction has reduced the demand for coal-tar enamel and with it the number of skilled and experienced applicators available to apply it in the field. To an outside observer, the application of coal-tar enamel in the field might appear to be a low-tech and low-skilled occupation. Low-tech, maybe. Low-skill, definitely not. Reclamation's replacement for coal-tar enamel has been coal-tar epoxies of the DOD-P-23236A, type I or III, class 2 type (not all of the coal-tar epoxies being specified currently by Reclamation conform totally to this specification). Interestingly, coal-tar epoxies conforming to this specification are high solids and relatively low VOC (about 68 percent and 299 grams per liter [1.5 lb/per gal], respectively). In a real sense, the DOD specification epoxies were Reclamation's introduction to the brave new world of high solids, low VOC coatings systems, just as coal-tar enamel was an introduction to 100 percent solids coatings systems.

More so than with the other types of coatings systems which were investigated, 100 percent solids coatings are application-equipment dependent. Even many of those coatings which can be applied with basic airless spraying equipment benefit from the use of such special items as heated coating delivery lines. Because no added solvent is present for viscosity control, heat must be used if the coatings are to be applied in their 100 percent solids condition under less than warm conditions. A problem with many 100 percent solids coatings systems is their inability to flow out and wet the substrate, under many of the same temperature conditions, as well as conventional (high VOC) or even high solids (low VOC) coatings are capable of doing. If thinner is added to 100 percent solids coatings systems, they are no longer 100 percent solids with negligible VOC. Consequently, appropriate application equipment must be used to compensate for the limitations inherent in 100 percent solids coatings systems. The short to extremely rapid curing cycles of some of these systems make the use of some type of plural component spraying equipment mandatory. VOC and safety considerations are expected to stimulate the use and development of 100 percent solids coatings and waterborne coatings, along with galvanizing, powder coatings (Holder and Chan, 1988) and metallizing coatings (Race et al., 1989) in at least the foreseeable future.

Laboratory investigations are, of course, only one facet of a complete, overall coatings management program. An examination of this extensive and important subject is beyond the scope of this report. The *JPCL* (*Journal of Protective Coatings and Linings*) is a good source of information on coatings management programs. A system for monitoring and evaluating coatings systems by Reclamation field offices is outlined in the most recent DOC (Designer's Operating Criteria) documents prepared for Reclamation field installations.

Regardless of the operating mechanisms of a coatings management program, its main objective is to achieve satisfactory protection and/or beautification of the surfaces being coated in conformance with health, safety, and environmental regulations, and in as economical a manner as is possible. The proper economic measure is cost per square meter (cost per square foot)/year of satisfactory service. Proper maintenance of the coatings systems is included. This ideal may not always be feasible in the real world because of budgeting systems and constraints, which make up front costs more important than they should be from the ideal point of view. However, by recognizing the ideal, more knowledgeable, and perhaps more effective, compromises can be chosen.

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APPENDIX A

Tables

Table 1RLR. – Coatings roster and characteristics.

System No.	Generic type	Volume solids (%)	Target DFT (min.) (mils)	No. of coats	Passed 1,454 hr (min.) FW immersion	Visual color	VOC content (g/L)[6]
1-1 (control)	Red lead primer[1] (TT-P-8GG, type IV)	53.3	1.5	1	No	Orange	370
1-2	Red lead primer	53.3	1.5	1	---	---	370
(control)	Phenolic aluminum topcoat[2]	51.1	3.0	2	Yes	Aluminum	391
1-3	Red lead primer	53.3	1.5	1	---	---	370
(control)	Silicone alkyd topcoat[3]	45.0	3.0	2	Yes	Green	420
2-1	Phenolated alkyd-zinc phosphate, iron oxide, mica primer[4]	32.4	1.5	1	Yes	Brown	593
2-2	Phenolated alkyd-zinc phosphate, iron oxide, mica primer	32.4	1.5	1	---	---	593
	Phenolic aluminum topcoat	51.1	3.0	2	No	Aluminum	391
2-3	Phenolated alkyd-zinc phosphate, iron oxide, mica primer	32.4	1.5	1	---	---	593
	Silicone alkyd topcoat	45.0	3.0	2	No	Green	240
3-1	Phenolated alkyd-zinc phosphate, iron oxide, mica primer[4]	42.0	1.5	1	Yes	Brown	453
3-2	Phenolated alkyd-zinc phosphate, iron oxide mica primer	42.0	1.5	1	---	---	453
	Phenolic aluminum topcoat	51.1	3.0	2	No	Aluminum	391
3-3	Phenolated alkyd-zinc phosphate, iron oxide, mica primer	42.0	1.5	1	---	---	453
	Silicone alkyd topcoat	45.0	3.0	2	No	Green	420
4-1	Cold cut phenolic varnish-zinc phosphate, iron oxide, platey talc primer[5]	66.5-68.0	1.5	1	Yes	Brown	250
4-2	Cold cut phenolic varnish-zinc phosphate, iron oxide, platey talc primer	66.5-68.0	3.0	2	---	---	250
	Phenolic aluminum topcoat	51.1	1.5	1	No	Aluminum	391
4-3	Cold cut phenolic varnish-zinc phosphate, iron oxide, platey talc primer	66.5-68.0	1.5	1	---	---	250
	Silicone alkyd topcoat	45.0	3.0	2	Yes	Green	420

[1] TT-P-86G, type IV red lead primer.
[2] TT-P-119D mixing varnish/TT-P-320D, type 2, class B aluminum paste.
[3] TT-E-490E silicone alkyd semigloss enamel.
[4] Commercially available primer.
[5] State of California formula PB-193 [now, with adjustments, PB-201 (red) and PB-202 (pink)].
[6] g/L = grams per liter.

Table 2RLR. — Immersion test results - duplicate panels.

Primer No. - panel No.	Total dry-film thickness			First blisters appeared (hr)	Blister size and frequency[3]	Total immersion time (hr)	Final blister size and frequency	Adhesion rating[4] non-immersed		After immersion	
	Primer	Phen. Alum[1]	TT-E-490E[2]					Cut only	Cut and taped	Cut only	Cut and taped
1 - 1a[5]	1.6	---	---	312	8, few	1,536	6, few	3B	3B	4B	3B
1 - 1b	1.5	---	---	312	8, few	1,536	8, few	5B	4B	4B	3B
1 - 2a	1.4	4.3	---	none	---	1,542	none	0B	0B	0B	0B
1 - 2b	1.6	4.3	---	none	---	1,542	none	0B	0B	0B	0B
1 - 3a	1.6	---	4.6	none	---	1,536	none	0B	0B	0B	0B
1 - 3b	1.7	---	4.6	none	---	1,536	none	0B	0B	0B	0B
2 - 1a	1.7	---	---	none	---	1,608	none	5B	5B	5B	5B
2 - 1b	1.6	---	---	none	---	1,608	none	5B	5B	5B	5B
2 - 2a	1.4	4.7	---	936	6, few	1.434	6, few	2B	2B	0B	0B
2 - 2b	1.7	4.7	---	1,104	6, few	1,434	6, few	5B	4B	4B	4B
2 - 3a	1.5	---	4.4	1,104	4, 6, few	1,434	4, 6, few	3B	3B	4B	2B
2 - 3b	1.4	---	4.4	408	4, 6, few	1,434	4, 6, few	3B	3B	3B	3B
3 - 1a	1.5	---	---	none	---	1,536	none	5B	5B	2B	0B
3 - 1b	1.8	---	---	none	---	1,536	none	5B	5B	1B	0B
3 - 2a	1.5	4.5	---	1,128	6, few	1,536	4, 6, 8 few	4B	3B	0B	0B
3 - 2b	1.5	4.4	---	504	6, few	1,536	4, 6, 8 few	5B	5B	1B	1B
3 - 3a	1.5	---	4.3	480	6, few	1,536	4, few; 6, few; 8, few	2B	2B	0B	0B
3 - 3b	1.9	---	4.6	480	6, few	1,536	4, few; 6, few; 8, few	4B	4B	3B	2B
4 - 1a	1.5	---	---	none	---	1,608	none	5B	5B	5B	4B
4 - 1b	1.5	---	---	none	---	1,608	none	5B	5B	5B	5B
4 - 2a	1.8	4.5	---	1,320	4, med	1,434	4, med	4B	4B	3B	2B
4 - 2b	1.8	4.6	---	1,320	4, med	1,434	4, med	5B	5B	3B	2B
4 - 3a	1.8	---	4.5	none	---	1,434	none	4B	4B	0B	0B
4 - 3b	1.8	---	4.3	none	---	1,434	none	4B	4B	4B	4B

[1] TT-V-119D mixing varnish/TT-P-3200, type 2, class B aluminum paste.

[2] TT-E-490E silicone alkyd semigloss enamel.

[3] Ratings are from "Pictorial Standards of Coatings Defects," published by the Federation of Societies for Coatings Technology. Blisters rated 2 are the largest, blisters rated 8 are the smallest.

[4] See table 3RLR for additional details on the type of loss of adhesion which occurred. A rating of 5B indicates no loss of adhesion, a rating of 0B indicates a loss of adhesion of greater than 65 percent of the test area.

[5] Panels a and b are duplicate panels.

Table 3RLR. — Adhesion test results - duplicate panels.

Primer No. - panel No. and topcoat		Non-immersion (control)			After immersion				After QUV exposure[7]		
		Principal plane of failure	Cut and taped[5]	Principal plane of failure[6]	Cut only[3]	Principal plane of failure[4]	Cut and taped[5]	Principal plane of failure[6]	Cut only	Cut and taped	Principal plane of failure
1 - 1a	none	Substrate	3B	NC	4B	Substrate	3B	Substrate	5B	5B	---
1 - 1b	none	---	4B	Substrate	4B	Substrate	3B	Substrate	5B	5B	---
1 - 2a	Phen. alum[1]	Substrate	0B	NC	0B	Substrate	0B	NC	---	---	---
1 - 2b	phen. alum	Substrate	0B	NC	0B	Substrate	0B	NC	---	---	---
1 - 3a	TT-E-490E[2]	Substrate	0B	NC	0B	Substrate	0B	NC	---	---	---
1 - 3b	TT-E-490E	Substrate	0B	NC	0B	Substrate	0B	NC	---	---	---
2 - 1a	none	---	5B	---	5B	---	5B	---	5B	5B	---
2 - 1b	none	---	5B	---	5B	---	5B	---	5B	5B	---
2 - 2a	Phen. alum	Substrate	2B	NC	0B	Substrate	0B	NC	---	---	---
2 - 2b	Phen. alum	---	4B	Substrate	4B	Substrate	4B	NC	---	---	---
2 - 3a	TT-E-490E	Substrate	3B	NC	3B	Substrate	2B	Substrate	---	---	---
2 - 3b	TT-E-490E	Substrate	3B	NC	3B	Substrate	3B	NC	---	---	---
3 - 1a	none	---	5B	---	2B	Substrate	0B	Substrate	5B	5B	---
3 - 1b	none	---	5B	---	1B	Substrate	0B	Substrate	5B	5B	---
3 - 2a	Phen. alum	Intercoat	3B	Intercoat	0B	Substrate	0B	NC	---	---	---
3 - 2b	Phen. alum	---	5B	---	1B	Substrate	1B	NC	---	---	---
3 - 3a	TT-E-490E	Substrate	2B	NC	0B	Substrate	0B	NC	---	---	---
3 - 3b	TT-E-490D	Intercoat	4B	NC	3B	Substrate	2B	Intercoat	---	---	---
4 - 1a	none	---	5B	---	5B	---	4B	Substrate	5B	5B	---
4 - 1b	none	---	5B	---	5B	---	5B	---	5B	5B	---
4 - 2a	Phen. alum	Intercoat	4B	NC	3B	Intercoat	2B	Intercoat	---	---	---
4 - 2b	Phen. alum	---	5B	---	3B	Intercoat	2B	Intercoat	---	---	---
4 - 3a	TT-E-490E	Intercoat	4B	NC	0B	Intercoat	0B	NC	---	---	---
4 - 3b	TT-E-490E	Intercoat	4B	NC	4B	Intercoat	4B	NC	---	---	---

1 TT-V-119D mixing varnish/TT-P-3200, type 2, class aluminum paste.

2 TT-E-490E silicone alkyd semigloss enamel.

3 A rating of 5B indicates no loss of adhesion, a rating of 0B indicates a loss of adhesion of greater than 65 percent of the test area.

4 The principal plane of failure, substrate or intercoat, was the plane where the majority of coating disbondment took place. If the bond was broken at the substrate, the adhesion of the topcoat to the primer was stronger than the adhesion of the primer to the substrate. If the adhesion of the primer to the substrate was stronger than the adhesion of the topcoat to the primer, "Intercoat" was the principal plane of failure.

5 If the "cut and taped" rating is the same as the "cut only" rating, no further loss of adhesion from the crosshatched area was noted after the tape had been applied and pulled back. "Cut and taped" is the official rating from the standard test.

6 NC = no change in the plane of failure.

7 Although the panels were wiped with a rag to remove loose carbonate or chalk, the partially bound, but loose, pigment particles which remained may have released during the "cut and taped" phase of the test, making it less severe.

Table 4RLR. — QUV accelerated weathering test results - duplicate panels (primers only).

Primer No. - panel No.	Dry-film thickness (mils)	First rusting appeared (hr)[1]	First discoloration appeared (hr)	Rusting increase 1,752 hr	Discoloration increase 1,752 hr	Rusting increase 3,005 hr	Discoloration increase 3,005 hr	Type of discoloration[2]	Rust creep under scribe	Adhesion rating 3,005 hr	
										Cut only	Cut and[3] taped
1 - 1a	1.7	369 (scr.)	369	slight (scr.) spots (scat.)	heavy	none	heavy	carbonate	none	5B	5B
1 - 1b	1.8	369 (scr.)	369	slight (scr.) spots (scat.)	heavy	none	heavy	carbonate	none	5B	5B
2 - 1a	1.6	369 (scr.)	369	slight (scr.)	slight	slight (scr.)	slight	chalking	none	5B	5B
2 - 1b	1.7	369 (scr.)	369	slight (scr.) spots (edge)	slight	slight (scr.) slight (spots)	slight	chalking	none	5B	5B
3 - 1a	1.8	369 (scr.)	369	medium (scr.) spots (edge)	slight	medium (scr.) slight (spot)	v. slight	chalking	none	5B	5B
3 - 1b	1.7	369 (scr.)	369	medium (scr.) spots (edge)	slight	medium (scr.) slight (spots)	v. slight	chalking	none	5B	5B
4 - 1a	1.8	369 (scr.)	369	slight (scr.)	medium	none	heavy	chalking	none	5B	5B
4 - 1b	1.7	369 (scr.)	369	slight/med. (scr.)	medium	none	heavy	chalking	none	5B	5B

[1] Abbreviations are: Scr. = scribe, scat. = scattered, med. = medium, v. = very, hr = hours

[2] Red lead changes from the oxide to the carbonate form during atmospheric exposure. A thin, but very noticeable, layer of carbonate (confirmed by an acid test) formed on the panels. The whitening which took place on the other panels represented conventional chalking, i.e., the loosening of surface pigment layers as the surface layers of binder deteriorate.

[3] The chalky condition of the test panels, even after cleaning, may have interfered with the adhesion of the tape to the crosshatched test area.

Table 5RLR. — Summary of all tests - duplicate panels averaged.

Primer No. topcoat	General application and film properties[1]	24-Hour recoating properties[1]	Immersion-blistering properties	Immersion hours (total)	Adhesion properties[2]			QUV accelerated weathering properties			
					Before immersion (ctrl)	After immersion	After QUV	Rusting (3,005 hours) Scribe	Spots	Creep	Discoloration (3,005 hr)
1 - 1 - Untopcoated	good	---	8, few	1,536	3.8B	3.5B	5.08	slight	scat	none	hv. carbonation
1 - 2 - Phen. alum.	good	good	none	1,542	0.0B	0.0B	---	---	---	---	---
1 - 3 - TT-E-490E	good	good	none	1,536	0.0B	0.0B	---	---	---	---	---
2 - 1 - Untopcoated	good	---	none	1,608	5.0B	5.0B	5.08	slight	edge	none	sl. chalking
2 - 2 - Phen alum.	good	good	6, few	1,434	3.3B	2.0B	---	---	---	---	---
2 - 3 - TT-E-490E	good	good	4, 6, few	1,434	3.0B	2.8B	---	---	---	---	---
3 - 1 - Untopcoated	good	---	none	1,536	5.0B	1.0B	5.08	medium	edge	none	v. sl. chalking
3 - 2 - Phen. alum.	good	good	4, 6, 8, few	1,536	4.3B	0.5B	---	---	---	---	---
3 - 3 - TT-E-490E	good	good	4, few; 6, few; 8 med.	1,536	3.0B	1.3B	---	---	---	---	---
4 - 1 - Untopcoated	good	---	none	1,608	5.0B	4.8B	5.08	sl/med	none	none	hv. chalking
4 - 2 - Phen. alum.	good	good	4, med.	1,434	4.5B	2.5B	---	---	---	---	---
4 - 3 - TT-E-490E	good	good	none	1,434	4.0B	2.0B	---	---	---	---	---

[1] The application properties of the adjusted formulation of primer No. 4, which was received after the main body of tests had been completed, are given. The adjusted sample contained xylol instead of butanol as one of the solvents and an adjustment in the drying catalysts.

[2] For a description of the principal planes of failures, see table 3RLR.

Table 1X. — Coating roster and characteristics.

System No.	Generic type	Volume solids (%)	Target DFT (min.) (mils)[1]	Number of coats	Passed 3,000 hr FW imm.[3]	Passed 3,000 hr SW imm.[3]	Visual color	VOC content (g/L)[2]
	Cracker tar extended aromatic polyurethane for shop application (coal-tar epoxy alternative)	97-99	25-30	1	Yes	No	Black	Negligible
2X	Epoxy-cycloaliphatic amine cured	100	12-14	2	Yes	No	Red	Negligible
3X	Epoxy-amine adduct cured	80	13	2	Yes	No	Gray	170
4X	Moisture cure polyurethane Zinc-rich primer aromatic, refined tar int. - topcoat	62.2 61.0	3-4 12	1 2	Yes	Yes	Black	335 335
5X	Hydrocarbon resin modified epoxy-polyamide (coal-tar epoxy alternative)	65	16	2	Yes	Yes	Black	302
6X	Epoxy-polyamidoamine high-build	69	16	2	Yes	Yes	Lt. gray	269-275
7X	Epoxy-polyamidoamine high-build HS	83	16	2	Yes	No	Lt. gray	121-142
8X	System No. 6X with an acrylic aliphatic polyurethane topcoat	(Basecoat) 69 (Topcoat) 69	16 3	2 3	Yes	No	Lt. gray	269-275 222-253
9X	Moisture cure polyurethane Zinc-rich primer Aromatic intermediate coat Aliphatic topcoat	62.2 63.0 63.0	3-4 4 3	1 1 1	Yes	Yes (1 panel)	Med. gray	335 335 335
10X	Moisture cure polyurethane Aromatic refined tar	61.0	18	3	Yes	Yes	Black	335
11X	Moisture cure polyurethane Aromatic primer-intermediate coat Aliphatic Topcoat	63.0 63.0	8 4	2 1	No	Yes	Med. gray	335 335
12X	Filled epoxy	100.0	20	2	Yes (1 panel)	Yes	Med. gray	Negligible
13W	Waterborne catalyzed epoxy for immersion	56.5	10	2	Yes	Yes	Green	39

[1] DFT = Dry-film thickness.
[2] VOC = Volatile organic compounds
[3] FW = Fresh water, SW = Salt water

Table 2X. — Physical properties

System No.	Average DFT (mils)	Adhesion rating (lb/in²)	(kPa)	1-Inch Mandrel bend test[1]	Application characteristics (all test panels)	Comments (adhesion)
1X	27.9	---	---	NC	Satisfactory (for shop application)	---
1X	27.9	200	1,379	---		100% to substrate
2X	13.8	---	---	LC, LA	Satisfactory	---
2X	13.6	150	1,034	---		100% to substrate
3X	13.8	---	---	LC	Satisfactory	---
3X	13.8	500	3,448	---		75% substrate 25% substrate
4X	15.4	---	---	S	Satisfactory	3% glue line
4X	15.6	107	738	---		97% within primer
5X	15.2	---	---	VS	Satisfactory	---
5X	15.0	250	1,724	---		100% intercoat and intracoat
6X	16.4	---	---	S-M	Satisfactory	---
6X	16.3	110	758	---		100% intercoat and intracoat
7X	16.8	---	---	S-M	Satisfactory	---
7X	16.7	300	2,069	---		100% intercoat and intracoat
8X	18.5	---	---	S-M	Satisfactory	---
8X	18.5	299	2,061	---		90% intercoat and intracoat 10% glue line
9X	15.6	---	---	S	Satisfactory	---
9X	16.3	125[3]	862[3]	---		100% intercoat[3] and intracoat
10X	15.0	---	---	VF	Satisfactory	---
10X	14.9	140	965	---		100% intercoat and intracoat
11X	17.6	---	---	S	Satisfactory	---
11X	16.2	160	1,103	---		100% intercoat and intracoat
12X	12.9	---	---	VF	Questionable[2]	---
12X	13.1	425	2,930	---		83% glue line 15% intercoat 2% substrate
13W	11.3	---	---	NC	Satisfactory	---
13W	11.1	200	1,379	---		90% substrate 100% intercoat

[1] VF = very fine cracks, S = small cracks, S-M = small to medium cracks, LC = large cracks, NC = no cracks, and LA = loss of adhesion at substrate.

[2] The panels were not fully coated, as instructed, and DFTs were significantly below the target DFTs. Runs, floating were visible on the panels. It is possible that proper, recommended, coating procedures may have resulted in satisfactory application.

[3] Has same zinc-rich primer as system No. 4X.

Table 3X. — QUV accelerated weathering test - color data and chalk rating (average of duplicate panels).

	QUV color data (initial)						QUV color difference (3,000 hours)[1]					
System No.	Avg. DFT (mils)	Illuminant	L^*	a^*	b^*	Visual color initial	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	Chalk rating 3,000 hours
1X	27.8	C	24.87	-2.30	1.66	Black	-11.23	0.74	-0.68	11.28	4
1X		D65	24.52	0.19	-0.05		-10.81	0.00	-0.40	10.82	
2X	13.9	C	34.50	21.81	17.89	Red	1.77	-5.91	-4.75	7.85	2
2X		D65	33.30	26.19	17.64		2.90	-7.55	-6.85	10.63	
3X	13.8	C	58.07	-6.56	6.92	Gray	14.18	0.41	1.31	14.25	4
3X		D65	58.09	-2.41	3.80		15.51	1.09	0.42	15.56	
4X	15.5	C	30.36	-2.15	0.98	Black	-4.13	0.61	-0.45	4.20	8
4X		D65	30.28	-0.46	-0.99		-3.74	0.41	-0.39	3.80	
5X	14.3	C	28.92	-2.11	2.06	Black	28.55	-0.66	3.12	28.74	3
5X		D65	28.65	0.47	0.17		29.51	0.95	1.87	29.59	
6X	17.5	C	71.31	-7.13	4.28	Lt. gray	8.10	0.35	2.46	8.47	2
6X		D65	71.42	-2.32	0.57		8.08	1.04	2.23	8.45	
7X	16.3	C	70.14	-6.17	3.89	Lt. gray	6.47	-0.12	3.67	7.44	4
7X		D65	70.28	-1.32	0.15		6.39	0.23	3.54	7.31	
8X	19.7	C	71.05	-6.65	4.20	Lt. gray	5.00	0.13	-0.54	5.03	6
8X		D65	71.23	-1.76	0.45		4.76	0.31	-0.74	4.82	
9X	14.8	C	56.03	-4.62	6.11	Med. gray	12.14	-0.42	3.56	12.65	6
9X		D65	56.43	-0.55	3.13		11.74	0.23	3.06	12.14	
10X	NT(4X)	NT(4X)[3]	---	---	---	Black	---	---	---	---	NT(4X)
10X			---	---	---		---	---	---	---	
11X	NT(9X)	NT(9X)	---	---	---	Med. gray	---	---	---	---	NT(9X)
11X			---	---	---		---	---	---	---	
12X	11.5	NT[4]	---	---	---	Med. gray	---	---	---	---	6
12X			---	---	---		---	---	---	---	
13W	10.6	C	57.61	-16.31	17.23	Green	11.73	5.26	-1.33	12.92	2
13W		D65	57.62	-12.27	14.42		11.75	6.12	-1.90	13.38	

[1] ΔL^*, lighter; $-\Delta L^*$, darker; Δa^*, redder; $-\Delta a$, greener; Δb^*, yellower; $-\Delta b^*$, bluer; $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*) + (\Delta b^*)^2]^{1/2}$.

[2] 10 = no chalking, 0 = very heavy chalking.

[3] NT = not tested. Number which follows in the parenthesis means that the topcoat is the same as the numbered tested topcoat. For example, NT(4X) means that system No. 10X, in this instance, has the same topcoat as was tested for system No. 4X.

[4] System No. 12X was not tested for color because of the floating present, and because some of the standard test areas were not coated with the system to be tested.

Table 4X. — Immersion tests - blistering and rusting (scribe lines) data.

System No. Panel No.	Saltwater immersion					Freshwater (deionized) immersion				
	Average DFT (mils)	Initial blistering (hours)[2]	100% rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion)[1]	Average DFT (mils)	Initial blistering (hours)[3]	100% rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion)[1]
1X - 1	25.3	1,170	2,840	3,175	4 No. 4	30.8	---	160	17,261	---
1X - 2	30.0	328	2,840	3,175	3 No. 4	24.5	---	160	17,261	---
Average or comments	27.7	749	2,840	3,175	2 No. 2 + (back) on panel No. 2	27.7	---	160	17,261	---
2X - 1	13.5	2,829	2,829	3,000	3 No. 4	13.6	---	161	17,137	---
2X - 2	13.5	1,704	2,829	3,000	1 No. 2	13.6	---	161	17,137	---
Average or comments	13.5	2,267	2,829	3,000	N.B.O.B.[2]	13.6	---	161	17,137	---
3X - 1	13.0	2,488	2,829	3,000	2 No. 4, 1 No. 2	13.6	---	161	16,000	---
3X - 2	13.0	2,488	2,829	3,000	2 No. 4	13.6	---	161	16,000	---
Average or comments	13.0	2,488	2,829	3,000	1 No. 4 (back) on panel No. 1	13.6	---	161	16,000	---
4X - 1	16.6	---	931	3,080	---	16.5	---	3,026+	3,026	---
4X - 2	16.3	---	931	3,080	---	16.2	---	161	3,026	---
Average or comments	16.0	---	931	3,080	---	15.9	---	1,594+	3,026	---
5X - 1	15.5	---	3,423	12,232	---	16.0	---	342	12,232	---
5X - 2	16.2	---	3,423	12,232	---	15.6	---	342	12,232	---
Average or comments	15.9	---	3,423	12,232	---	15.8	---	342	12,232	---
6X - 1	17.2	---	3,198	3,389	---	17.7	---	209	3,007	---
6X - 2	17.2	---	3,198	3,389	---	16.4	---	209	3,007	---
Average or comments	17.2	---	3,198	3,389	---	17.1	---	209	3,007	---
7X - 1	16.8	1,343	1,343	3,030	4 No. 4	16.5	---	209	3,007	---
7X - 2	15.8	1,343	1,343	3,030	2 No. 2	15.8	---	209	3,007	---
Average or comments	16.3	1,343	1,343	3,030	N.B.O.B.	16.2	---	209	3,007	---

Table 4X. — Immersion tests - blistering and rusting (scribe lines) data - continued.

System No. Panel No.	Saltwater immersion					Freshwater (deionized) immersion				
	Average DFT (mils)	Initial blistering (hours)[2]	100% rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion)[1]	Average DFT (mils)	Initial blistering (hours)[3]	100% rusting in scribe lines (hours)[3]	Total hours completed	Blister size and frequency (completion)[1]
8X - 1	19.4	1,343	1,343	3,090	2 No. 2	19.1	---	209	3,007	---
8X - 2	21.9	1,343	1,343	3,090	3 No. 2	20.5	---	209	3,007	---
Average or comments	20.7	1,343	1,343	3,090	N.B.O.B	19.8	---	209	3,007	---
9X - 1	15.7	---	931	3,080	4 No. 4	15.8	---	2,359	3,026	---
9X - 2	14.2	2,623	931	3,080	1 No. 6	15.4	---	2,359	3,026	---
Average or comments	15.0	---	931	3,080	N.B.O.B.[2]	15.6	---	2,359	3,026	---
10X - 1	185.	---	3,080+	3,080	---	15.4	---	161	3,026	---
10X - 2	15.4	3,080	3,080+	3,080	1 No. 2	15.4	---	161	3,026	---
Average or comments	17.0	---	3,080+	3,080	N.B.O.B.	15.4	---	161	3,026	---
11X - 1	14.3	---	3,080+	3,080	---	16.1	2,004	498	3,026	2 No. 4
11X - 2	15.6	---	3,080+	3,080	---	15.4	2,004	498	3,026	4 No. 4
Average or comments	15.0	---	3,080+	3,080	---	15.8	2,004	498	3,026	N.B.O.B.
12X - 1	15.0	---	18	3,080	---	18.0	---	1,022	3,026	(1 No. 2)
12X - 2	16.3	---	18	3,080	---	15.2	2,880	1,022	3,026	(6 No. 4) 12X - 2 only
Average or comments	15.7	---	18	3,080	---	16.6	1,440	1,022	3,026	N.B.O.B.
13W - 1	10.3	---	479	5,626	---	10.6	---	209	7,054	---
13W - 2	10.6	---	479	5,626	---	10.2	---	209	7,054	---
Average or comments	10.5	---	479	5,626	---	10.4	---	209	7,054	---

1 *Pictorial Standards of Coatings Defects* and ASTM D 714-87. The largest number refers to the smallest blister on a scale of 2-8 (2 = large, 8 = small).

2 N.B.O.B. = No blistering on back of panel.

3 The number of hours recorded are the number of hours of exposure as of the time the panels were examined. The exact number of hours before blistering or rusting rook place are unknown. However, in no instance would the number of hours be less than the recorded number of hours by more than 1 week's exposure time, approximately 164 to 168 hours.

Table 5X. — Immersion tests data - color change.

System No. Panel No. SW or FW[1]	Average DFT (mils)	Hours of immersion before color was checked	Illuminant (for panels 1 and 2)	CIE 1976 CIELAB *L* a* b** color date (average of duplicate panels)[2] Before immersion			Visual color	Color difference (after immersion)				Panel will continue in immersion test?	
				L*	a*	b*		ΔL*	Δa*	Δb*	ΔE*	Yes	No
1X - 1SW	25.3	3,175	C	23.95	-2.04	1.70	Black	6.47	-1.34	0.37	6.63		X
1X - 2SW	30.0	3,175	D65	24.92	0.01	0.14		5.58	-0.88	0.02	5.72		X
Average:	27.7	3,175		---	---	---		---	---	---	---		
1X - 1FW	30.8	~3,000	C	24.21	-2.25	2.04	Black	9.96	-1.35	3.48	10.69	X	
1X - 2FW	24.5	~3,000	D65	24.36	0.07	0.14		9.62	-0.53	3.13	10.16	X	
Average:	27.7	~3,000		---	---	---		---	---	---	---		
2X - 1SW	13.5	3,000	C	34.18	22.02	18.45	Red	-0.78	-0.06	-0.42	0.90		X
2X - 2SW	13.5	3,000	D65	33.37	26.08	17.32		1.14	-1.73	-2.14	2.99		X
Average:	13.5	3,000		---	---	---		---	---	---	---		
2X - 1FW	13.6	~3,000	C	35.50	20.84	17.19	Red	-0.57	-0.33	-0.45	1.53	X	
2X - 2FW	13.6	~3,000	D65	35.59	24.11	15.14		-0.31	-0.29	-0.37	0.85	X	
Average:	13.6	~3,000		---	---	---		---	---	---	---		
3X - 1SW	13.0	3,000	C	58.30	-6.44	6.53	Gray	-0.22	0.08	1.05	1.08		X
3X - 2SW	13.0	3,000	D65	58.33	-2.28	3.42		-0.16	0.05	1.26	1.28		X
Average:	13.0	3,000		---	---	---		---	---	---	---		
3X - 1FW	13.6	~3,000	C	57.73	-6.36	6.86	Gray	-0.52	0.17	1.06	1.29	X	
3X - 2FW	13.6	~3,000	D65	57.83	-2.26	3.81		-0.45	0.18	0.93	1.08	X	
Average:	13.6	~3,000		---	---	---		---	---	---	---		
4X - 1SW	15.6	3,080	C	30.18	-2.15	1.07	Black	0.94	0.33	1.99	2.23	X	
4X - 2SW	16.3	3,080	D65	30.16	0.44	-0.97		0.99	0.46	2.00	2.29	X	
Average:	16.0	3,080		---	---	---		---	---	---	---		
4X - 1FW	15.5	3,026	C	30.42	-2.22	1.34	Black	3.26	0.22	1.94	3.83	X	
4X - 2FW	16.2	3,026	D65	30.39	0.37	-0.78		3.38	0.36	1.94	3.96	X	
Average:	15.9	3,026		---	---	---		---	---	---	---		
5X - 1SW	15.5	~3,000	C	28.94	-2.24	1.96	Black	-2.78	3.57	3.78	5.90	X	
5X - 1SW	16.2	~3,000	D65	29.09	0.41	0.10		-1.35	3.40	4.58	6.07	X	
Average:	15.9	~3,000		---	---	---		---	---	---	---		

Table 5X. — Immersion tests data - color change - continued.

System No. Panel No. SW or FW[1]	Average DFT (mils)	Hours of immersion before color was checked	Illuminant (for panels 1 and 2)	CIE 1976 CIELAB *L* a* b** color date (average of duplicate panels)[2]								Panel will continue in immersion test?	
				Before immersion			Visual color	Color difference (after immersion)					
				L*	a*	b*		ΔL*	Δa*	Δb*	ΔE*	Yes	No
5X - 1FW	16.0	~3,000	C	30.30	-2.48	1.82	Black	2.66	4.13	9.02	10.27	X	
5X - 2FW	15.6	~3,000	D65	31.06	0.25	0.32		1.93	4.35	9.23	10.39	X	
Average:	15.8	~3,000		---	---	---		---	---	---	---		
6X - 1SW	17.2	~3,000	C	71.42	-7.17	4.26	Lt. gray	-12.18	7.81	29.27	32.79	X	
6X - 2SW	17.2	~3,000	D65	71.46	-2.31	0.53		-10.75	6.24	28.99	31.64	X	
Average:	17.2	~3,000		---	---	---		---	---	---	---		
6X - 1FW	17.7	~3,007	C	71.36	-7.15	4.28	Lt. gray	-4.80	2.80	16.50	17.51	X	
6X - 2FW	16.4	~3,007	D65	71.42	-2.31	0.56		-4.10	2.27	15.67	16.46	X	
Average:	17.1	~3,007		---	---	---		---	---	---	---		
7X - 1SW	16.8	3,030	C	70.56	-6.14	3.84	Lt. gray	-10.34	6.98	24.81	27.79		X
7X - 2SW	15.8	3,030	D65	70.61	-1.34	0.12		-11.82	8.37	26.32	30.06		X
Average:	16.3	3,030		---	---	---		---	---	---	---		
7X - 1FW	16.5	3,007	C	70.70	-6.16	3.80	Lt. gray	-3.78	1.03	17.89	18.32	X	
7X - 2FW	15.8	3,007	D65	70.62	-1.34	0.09		-3.51	0.85	18.09	18.45	X	
Average:	16.2	3,007		---	---	---		---	---	---	---		
8X - 1SW	19.4	3,091	C	71.27	-6.63	4.16	Lt. gray	-11.13	6.96	25.61	28.77		X
8X - 2SW	21.9	3,091	D65	71.25	-1.76	0.43		-9.21	4.81	23.93	26.09		X
Average:	20.7	3,091		---	---	---		---	---	---	---		
8X - 1FW	19.1	3,007	C	71.09	-6.59	4.18	Lt. gray	6.44	2.86	19.30	20.64	X	
8X - 1FW	20.5	3,007	D65	71.16	-1.78	0.47		6.64	2.81	20.35	21.67	X	
Average:	19.8	3,007		---	----	---		---	---	---	---		
9X - 1SW	15.7	3,080	C	56.38	-4.65	6.04	Med. gray	1.85	0.10	1.04	2.13	X	
9X - 2SW	14.2	3,080	D65	56.43	-0.59	3.01		1.78	0.17	1.00	2.05		X
Average:	15.0	3,080		---	---	---		---	---	---	---		
9X - 1FW	15.8	3,026	C	56.17	-4.67	6.12	Med. gray	0.07	0.79	5.47	5.66	X	
9X - 2FW	15.4	3,026	D65	56.23	0.56	3.09		-0.16	0.80	6.00	6.06	X	
Average:	15.6	3,026		---	---	---		---	---	---	---		

Table 5X. — Immersion tests data - color change - continued.

System No. Panel No. SW or FW[1]	Average DFT (mils)	Hours of immersion before color was checked	Illuminant (for panels 1 and 2)	CIE 1976 CIELAB L^* a^* b^* color date (average of duplicate panels)[2]								Panel will continue in immersion test?	
				Before immersion			Visual color	Color difference (after immersion)					
				L*	a*	b*		ΔL*	Δa*	Δb*	ΔE*	Yes	No
10X - 1SW	18.5	3,080	C	30.63	-2.15	1.23	Black	1.61	0.32	3.16	3.57	X	
10X - 2SW	15.4	3,080	D65	30.68	0.47	-0.82		1.68	0.36	3.27	3.70		X
Average:	17.0	3,080		---	---	---		---	---	---	---		
10X - 1FW	15.4	3,026	C	31.25	-2.22	1.37	Black	0.07	0.41	1.54	1.60	X	
10X - 2FW	15.4	3,026	D65	30.87	-0.43	-0.71		0.27	0.45	1.66	1.76	X	
Average:	15.4	3,026		---	---	---		---	---	---	---		
11X - 1SW	14.3	3,080	C	56.89	-4.65	6.03	Med. gray	-0.51	0.62	6.12	6.18	X	
11X - 2SW	15.6	3,080	D65	56.93	-0.59	2.97		-0.54	0.71	6.56	6.62	X	
Average:	15.0	3,080		---	---	---		---	---	---	---		
11X - 1FW	16.1	3,026	C	56.87	-4.69	5.95	Med. gray	-3.31	2.46	10.27	11.06		X
11X - 2FW	15.4	3,026	D65	56.93	-0.61	2.92		-3.37	2.37	10.79	11.55		X
Average:	15.8	3,026		---	---	---		---	---	---	---		
12X - 1SW	15.0	3,080	C	NT[4]	---	---	Med. gray	---	---	---	---	X	
12X - 2SW	16.3	3,080	D65	NT	---	---		---	---	---	---	X	
Average:	15.7	3,080		---	---	---		---	---	---	---		
12X - 1FW	18.0	3,026	C	NT	---	---	Med. gray	---	---	---	---	X	
12X - 2FW	15.2	3,026	D65	NT	---	---		---	---	---	---		X
Average:	16.8	3,026		---	---	---		---	---	---	---		
13W - 1SW	10.3	~3,000	C	58.20	-16.08	16.71	Green	1.15	1.43	1.43	1.89	X	
13W - 2SW	10.6	~3,000	D65	58.30	-11.95	13.79		1.08	1.75	1.75	2.10	X	
Average:	10.5	~3,000		---	---	---		---	---	---	---		
13W - 1FW	10.6	~3,000	C	58.18	-16.11	16.83	Green	-1.02	10.90	10.90	12.48	X	
13W - 2FW	10.2	~3,000	D65	58.24	-12.08	13.99		-1.13	11.11	11.11	12.67	X	
Average:	10.4	~3,000		---	---	---		---	---	---	---		

[1] SW = Salt water, FW = Fresh water.

[2] The CIE 1976 CIELAB L^* a^* b^* color date system is based on a three-dimensional color mapping system. The L*, or lightness, axis is perpendicular to the a^* (red), $-a^*$ (green), b^* (yellow), and $-b^*$ (blue) axes.

[3] The total color difference, ΔE^*_{ab}, was calculated using the method given in ASTM D 2244-85. The equation used to calculate ΔE^*_{ab} is $\Delta E^*_{ab} = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$.

[4] System No. 12X was not tested for color because of the floating present, and some of the standard test areas were not coated with the system to be tested.

Table 6X. — Summary of test data - average values for each coating system.

System No.	Total target (DFT) (min.) (mils)[1]	Saltwater immersion: Initial blistering (hr)[7]	Saltwater immersion: Total hours completed	Saltwater immersion: Total color difference (ΔE^*_{ab})[2]	(Deion.) water immersion: Initial blistering (hr)[7]	(Deion.) water immersion: Total hours completed	(Deion.) water immersion: Total color difference (ΔE^*_{ab})[2]	QVC acc. weathering: Chalk rating completed[3]	QVC acc. weathering: Total color difference (ΔE^*_{ab})[2]	Pulloff adhesion: (lbf/in)[2]	Pulloff adhesion: (kPa)	1-Inch mandrel: Cracking: Yes	1-Inch mandrel: Cracking: No	1-Inch mandrel: Some loss of adhesion?: Yes	1-Inch mandrel: Some loss of adhesion?: No	General coating properties: Min. number of coats	General coating properties: Min. curing time at 75 °F before immersion (days)	General coating properties: Method of application[4]	General coating properties: Type of coating system[5]: HS	General coating properties: Type of coating system[5]: HP
1X	25-30	749	3,175	6.63	CIT[6]	17,261	10.69	4	11.28	200	1,379		X		X	1	2	PCH shop only	SP	
2X	12-14	2,267	3,000	0.90	CIT	17,137	1.53	2	7.85	150	1,034	X		X		2	7	G45	SP	
3X	13	2,448	3,000	1.08	CIT	16,000	1.29	4	14.25	500	3,448	X			X	2	7	B,R,A		SP
4X	15-16	CIT[6]	3,080	2.23	CIT	3,026	3.83	8	4.20	107	738	X			X	3	1	B,R,C,A	P,T	
5X	16	CIT	12,232	5.90	CIT	12,232	10.27	3	28.74	250	1,724	X			X	2	7	B,R,C,A	SP	
6X	16	CIT	3,389	32.79	CIT	3,007	17.51	2	8.47	110	758	X			X	2	7	B,C,A	SP	
7X	16	1,343	3,030	27.79	CIT	3,007	18.32	4	7.44	300	2,069	X			X	2	7	B,R,C,A	SP	
8X	19	1,343	3,090	28.77	CIT	3,007	20.64	6	5.03	299	2,062	X			X	3	7	B,R,C,A (top)	P,I,T	
9X	10-11	2,623 (1 panel CIT)	3,080	2.13	CIT	3,026	5.66	6	12.65	125	862	X			X	3	1	B,R,C,A	P,I,T	
10X	18	3,080 (1 panel CIT)	3,080	3.57	CIT	3,026	1.60	NT (4X)[8]	NT (4X)[8]	140	865	X			X	3	1	B,R,C,A	SP	
11X	12	CIT	3,080	6.18	2,004	3,026	11.06	NT (9X)[8]	NT (9X)[8]	160	1,103	X			X	3	1	B,R,C,A	P,I,T	
12X	20	CIT	3,080	NT[8]	2,880 (1 panel CIT	3,026	NT[8]	6	NT[8]	425	2,930	X			X	2	3	B,HPHA	SP	
13W	10	CIT	5,626	1.89	CIT	7,054	12.48	2	12.92	200	1,379		X		X	2		B,C,A	SP(w)	

1 The values or information in these columns were supplied by or agreed to by the manufacturers of the coatings.
2 The total color differences, ΔE^*_{ab} were computed from the illuminant C readings. These readings were taken before immersion and exposure and at the end of the basic 3,000-hour immersion and exposure periods.
3 The chalk ratings are based on the visual in *Pictorial Standards of Coatings Defects*. A rating of 2 on the 2, 4, 6, 8, and 10 scale refers to very heavy chalking, while a rating of 10 refers to an absence of chalking.
4 C = conventional spray, A = airless spray, B = brush, R = roller, HPHA = high-pressure heated airless spray, PCH = plural compound (heated) spray, and G45 = Graco 45 airless spray.
5 HS = high solids, HP = 100 percent solids, P = primer, T = topcoat, SP = self priming, I = intermediate coat, and (w) = waterborne.
6 CIT = continuing in test.
7 The number of hours recorded are the number of hours of exposure as of the time the panels were examined. The exact number of hours before initial blistering took place are unknown. However, in no instance would the number of hours be less than the recorded number of hours by more than 1 week's exposure time, about 164 to 168 hours.
8 Not Tested. See tables 3X and 5X.

Table 1W. — Coatings roster and characteristics.

System No.[1]	Generic type	Volume solids (%)	Target DFT (mils)[2]	Number of coats	Passed 3,000-hr FW imm.?	Visual color (topcoat)	VOC content (g/L)[4]
1W	Alkyd and silicone alkyd						
(control)	TT-P-636D primer (alkyd)	45	1	1			416
	TT-E-490E topcoat (silicone alkyd)	45	3	2	N/A[3]	White	420
2W	Alkyd and silicone alkyd						
(control)	TT-P-664D primer (alkyd)	61	1	1			321
	TT-E-490E topcoat (silicone alkyd)	45	3	2	N/A	White	420
3W	Acrylic emulsion coating						
	Acrylic metal primer	40	3	1			240
	Acrylic gloss topcoat	39	3	2	N/A	White	250
4W	Acrylic emulsion coating						
	Acrylic primer/finish						
	All coats	49.5	6	2	N/A	White	67
5W	Acrylic emulsion coating						
	Acrylic primer/finish	49.5	3	1			67
	Acrylic gloss topcoat	39	3	2	N/A	White	250
6W	Acrylic/silicone alkyd						
	Acrylic metal primer	40	3	1			240
	TT-E-490E topcoat (Silicone Alkyd)	45	3	2	N/A	White	420
7W	Waterborne catalyzed epoxy						
	All coats	40	6	2	N/A	White	250
8W	Acrylic enamel/waterborne catalyzed epoxy						
	Acrylic metal primer	40	3	1			240
	S. G. epoxy topcoat	40	3	1	N/A	White	250
9W	Inorganic zinc/acrylic enamel						
	Waterborne zinc primer	68	1.5	1			
	Acrylic gloss topcoat	39	3	2	N/A	White	250
10W	Inorganic zinc/acrylic enamel						
	Waterborne zinc primer	68	1.5	1			---
	Acrylic (w/additive) int.	41	1.5	1			84
	Acrylic topcoat	41	1.5	1	N/A	White	84
11W	Inorganic zinc/acrylic enamel						
	Waterborne zinc primer	68	1.5	1			---
	Acrylic (w/additive) int.	41	1.5	1			84
	Acrylic topcoat	41	1.5	1	N/A	Dark gray	84
12W	Inorganic zinc/acrylic enamel						
	Waterborne zinc primer	68	1.5	1			---
	Acrylic primer/finish topcoat	49.5	3	2	N/A	White	67
13W	Waterborne catalyzed epoxy for immersion, all coats	56.5	10	2	Yes	Green	39
14W	Waterborne catalyzed epoxy						
	Waterborne epoxy primer	40	3	1			163
	Waterborne epoxy semigloss topcoat	40	6	2	No	White	250
15W	Acrylic emulsion coating						
	Acrylic primer	36	3	1			69
	Acrylic topcoat	36	3	1	N/A	White	57
16W	Acrylic emulsion coating						
	Acrylic primer	40	3	1			42
	Acrylic semigloss topcoat	34	3	2	N/A	White	100
17W	Acrylic emulsion coating						
	Acrylic primer	40	3	1			42
	Acrylic gloss topcoat	40	3	2	N/A	White	216

[1] The following system numbers have a common primer: 3W, 6W, 8W; 4W, 5W; 9W through 12W; 16W, and 17W. The following system numbers have a common topcoat: 1W, 2W, 6W; 3W, 5W, 9W; 7W, 8W; 4W, and 12W.
[2] DFT = dry-film thickness.
[3] N/A = Not applicable.
[4] VOC = Volatile organic compounds, g/L = grams per liter.

Table 2W. — Physical properties.

System No.	Average DFT (mils)	Adhesion rating[1]	1-Inch mandrel bend test	Primer early rust resistance (avg.)	Application characteristics
Control 1W	3.8	4B	---	---	Satisfactory
Control 1W	3.6	---	NC[2]	---	
Control 1W	---	---	---	N/A[3]	
Control 2W	4.0	2B	---	---	Satisfactory
Control 2W	4.6	---	Cracks along bed	---	
Control 2W	---	---	---	N/A	
3W	5.7	5B	---	---	Satisfactory
3W	6.1	---	NC	---	
3W	1.3	---	---	R&B[4]	
4W	5.7	5B	---	---	Satisfactory
4W	5.5	---	NC	---	
4W	2.0	---	---	B	
5W	5.7	5B	---	---	Satisfactory
5W	5.7	---	NC	---	
5W	---	---	---	NT(4)[5]	
6W	6.0	4B	---	---	Satisfactory
6W	6.0	---	NC	---	
6W	---	---	---	NT(3)	
7W	4.9	5B	---	---	Satisfactory
7W	4.7	---	NC	---	
7W	0.9	---	---	R&B	
8W	4.0	5B	---	---	Satisfactory
8W	3.8	---	NC	---	
8W	---	---	---	NT(3)	
9W	4.6	4B	---	---	Satisfactory
9W	4.5	---	NC	---	
9W	6.6	---	---	No R or B	
10W	4.3	5B	---	---	Satisfactory
10W	4.2	---	NC	---	
10W	---	---	---	NT(9)	
11W	3.1	4B	---	---	Satisfactory
11W	3.0	---	NC	---	
11W	---	---	---	NT(9)	
12W	4.5	0B	---	---	Satisfactory
12W	4.4	---	NC	---	
12W	---	---	---	NT(9)	
13W	11.1	200 psi (1,379 kPa)	---	---	Satisfactory
13W	11.3	---	NC	---	
13W	1.3	---	---	R&B	
14W	5.0[6]	5B	---	---	Satisfactory
14W	5.6	---	Sl. cracks along bend	---	
14W	---	---	---	No R or B	
15W	3.1	5B	---	---	Satisfactory[7]
15W	4.4	---	NC	---	
15W	---	---	---	No R or B	

Table 2W. — Physical properties - continued.

System No.	Average DFT (mils)	Adhesion rating[1]	1-Inch mandrel bend test	Primer early rust resistance (avg.)	Application characteristics
16W	4.0	5B	---	---	Satisfactory
16W	4.6	---	NC	---	
16W	---	---	---	No R or B	
17W	4.4	5B	---	---	Satisfactory
17W	4.6	---	NC	---	
17W	---	---	---	NT(16W)[5]	

[1] System Nos. 1W-12W and 14W-17W were given the cross-hatch adhesion test (5B best, 0B worst). System No. 13 was given the elcometer pulloff adhesion test.

[2] NC = No cracking.

[3] N/A = Not applicable.

[4] R = Rusting, B = blistering.

[5] NT = Not tested. Number which follows in the parentheses means that the primer is the same as the numbered tested primer. For example, NT(4) means that system No. 5, in this instance, has the same primer as was tested for system No. 4.

[6] System No. 14W had two target DFTs. One was for the QUV and immersion tests (9 mils) and the other was for the physical properties tested (6 mils).

[7] Sensitive to shipping and storage conditions.

Table 3W. - QUV accelerated weathering test - gloss and chalking data (averages of duplicate panels).

System No. Panel No.	Average DFT (mils)	Average[1] gloss (60°) Initial	Average[1] gloss (60°) 3,000 hr	Average % gloss retained 3,000 hr	Chalk rating[2] 3,000 hr
Control 1W-1[3]	4.2	48.0	13.0		8
Control 1W-2	4.2	47.0	12.0		8
Average:	4.2	47.5	12.5	26.3	8
Control 2W-1	4.0	32.0	12.0		4
Control 2W-2	4.0	38.0	10.0		6
Average:	4.0	35.0	11.0	31.4	5
3W-1	6.1	55.0	12.0		8
3W-2	5.7	58.0	10.0		8
Average:	5.9	56.5	11.0	19.5	8
4W-1	5.9	6.0	3.0		6
4W-2	5.8	5.0	3.0		6
Average:	5.9	5.5	3.0	54.5	6
5W-1	5.8	50.0	13.0		8
5W-2	6.1	52.0	11.0		8
Average:	6.0	51.0	12.0	23.5	8
6W-1	5.6	29.0	11.0		8
6W-2	6.1	30.0	10.0		8
Average:	5.9	29.5	10.5	35.6	8
7W-1	5.7	26.0	5.0		4
7W-2	5.7	28.0	4.0		4
Average:	5.7	27.0	4.5	16.7	4
8W-1	6.1	30.0	4.0		4
8W-2	5.9	24.0	3.0		4
Average:	6.0	27.0	3.5	13.0	4
9W-1	4.1	48.0	13.0		10
9W-2	4.3	53.0	11.0		8
Average:	4.2	50.5	12.0	23.8	9
10W-1	5.0	46.0	16.0		10
10W-2	4.1	46.0	17.0		10
Average:	4.6	46.0	16.5	35.9	10
11W-1	3.8	31.0	4.0		8
11W-2	3.8	28.0	5.0		8
Average:	3.8	29.5	4.5	15.3	8
12W-1	4.6	5.0	3.0		6
12W-2	4.4	5.0	3.0		6
Average:	4.5	5.0	3.0	60.0	6
13W-1	10.8	17.0	2.0		2
13W-2	10.4	13.0	2.0		2
Average:	10.6	15.0	2.0	13.3	2
14W-1	8.6	29.0	2.4		6
14W-2	8.6	26.0	2.5		6
Average:	8.6	27.5	2.5	9.1	6
15W-1	5.7	69.4	18.2		5
15W-2	5.9	74.7	10.3		5
Average:	5.8	72.1	14.3	19.8	5

Table 3W. - QUV accelerated weathering test - gloss and chalking data (averages of duplicate panels) - continued.

System No. Panel No.	Average DFT (mils)	Average[1] gloss (60°)		Average % gloss retained 3,000 hr	Chalk rating[2] 3,000 hr
		Initial	3,000 hr		
16W-1	4.6	45.6	15.5		9
16W-2	4.3	39.2	6.5		9
Average:	4.5	42.4	11.0	25.9	9
17W-1	4.1	71.1	5.5		8
17W-2	4.8	62.4	6.8		8
Average:	4.5	66.8	6.2	9.3	8

[1] Measured at 60° from the vertical: 100.0 = highest; 0.0 = lowest.

[2] 10 = No chalking; 0 = very heavy chalking.

[3] The following systems have the same topcoat: Control 1W, Control 2W, and No. 6W; Nos. 3W, 5W, and 9W; Nos. 4W and 12W; Nos. 7W, 8W, and 14W.

Table 4W. — QUV accelerated weathering test - color data (averages of duplicate panels).

System No.	Illuminant	QUV color data (initial)			QUV color change (3,000 hr)[1]				Visual color (initial)
		L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	
Control 1W	C	94.39	-7.12	9.68	0.06	0.42	-0.09	0.47	White
Control 1W	D65	94.45	-0.90	5.03	0.16	0.40	-0.36	0.58	White
Control 2W	C	92.64	-7.69	7.17	-0.31	0.41	-0.24	0.62	White
Control 2W	D65	92.76	-1.64	2.54	-0.47	0.45	-0.20	0.77	White
3W	C	92.20	-7.53	8.87	0.39	0.29	-0.03	0.50	White
3W	D65	92.56	-1.50	4.33	0.01	0.33	-0.19	0.43	White
4W	C	92.63	-7.20	6.12	-0.25	0.22	0.46	0.58	White
4W	D65	92.73	-1.14	1.58	-0.16	0.22	0.42	0.51	White
5W	C	92.41	-7.62	9.12	0.10	0.32	-0.05	0.42	White
5W	D65	92.56	-1.54	4.53	0.10	0.30	-0.29	0.44	White
6W	C	92.86	-7.45	8.24	-0.51	0.43	-0.50	0.95	White
6W	D65.0	92.97	-1.33	3.60	-0.55	0.42	-0.44	0.96	White
7W	C	92.61	-7.57	7.84	-1.64	0.80	3.46	2.91	White
7W	D65	92.65	-1.49	3.24	-1.49	0.74	3.50	3.87	White
8W	D	92.66	-7.52	8.03	-1.45	0.70	2.97	3.39	White
8W	D65	92.70	-1.45	3.48	-1.58	0.67	3.17	3.62	White
9W	C	92.25	-7.64	8.84	0.21	0.32	-0.26	0.47	White
9W	D65	92.41	-1.56	4.28	0.13	0.32	-0.36	0.50	White
10W	C	95.94	-7.61	5.42	-0.17	0.58	0.15	0.68	White
10W	D65	95.80	-1.34	0.64	0.11	0.54	0.16	0.58	White
11W	C	54.70	-4.97	-2.63	4.24	-0.58	-0.82	4.35	Dark gray
11W	D65	54.90	-1.09	-5.84	4.40	-0.39	-1.07	4.55	Dark gray
12W	C	92.37	-7.35	6.42	0.04	0.34	-0.08	0.52	White
12W	D65	92.72	-1.37	1.85	-0.23	0.42	-0.20	0.55	White
13W	C	57.61	-16.31	17.23	11.73	5.26	-1.33	12.92	Green
13W	D65	57.62	-12.27	14.42	11.75	6.12	-1.90	13.38	Green
14W	C	92.61	-7.22	7.68	-1.41	0.54	3.42	3.74	White
14W	D65	92.64	-1.23	3.09	-1.43	0.48	3.64	3.94	White
15W	C	94.40	-7.07	6.18	-0.04	0.40	0.82	0.91	White
15W	D65	94.46	-0.88	1.45	0.08	0.38	0.82	0.91	White
16W	C	96.71	-7.02	4.92	-0.11	0.52	0.41	0.70	White
16W	D65	96.93	-0.68	0.00	-0.44	0.48	0.49	0.83	White
17W	C	92.92	-6.72	3.55	0.30	0.06	1.46	1.49	White
17W	D65	93.00	-0.67	-1.15	0.32	0.11	1.50	1.54	White

[1] ΔL, darker; = $-\Delta L$, lighter; Δa, redder; $-\Delta a$, greener; Δb, yellower; $-\Delta b$, bluer; $\Delta E^*_{ab} = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$.

Table 5W. - Exterior exposure test - gloss, chalking, and thermal shock - 1 and 2 years exposure versus QUV accelerated weathering test.

System No. Panel No.	Avg. DFT (mils)	Average gloss (60°)[1]			Avg. gloss (60°) QUV (3,000 hr)	Average gloss retained %			Chalk rating[2]			Thermal shock, cycles w/o failure (EE[3] panels only)[4]	
		Initial	1 year	2 years		1 year	2 years	QUV (3,000 hr)	1 year	2 years	QUV (3,000 hr)	1 year	2 years
Control 1W-1	4.6	45.0	28.0	9.1	---	---	---	---	10	8	---	10	10
Control 1W-2	4.3	39.0	23.0	6.6	---	---	---	---	10	8	---	10	10
Control 1W-3	3.9	41.0	24.0	6.7	---	---	---	---	10	8	---	10	10
Control 1W-4	4.2	41.0	26.0	7.7	---	---	---	---	10	8	---	10	10
Average:	4.3	41.5	25.3	7.5	---	61.0	18.1	---	10	8	---	10	10
Control 1W (QUV avg.)	4.2	47.5	---	---	12.5	---	---	26.3	---	---	8	---	---
Control 2W-1	3.9	30.0	21.0	6.8	---	---	---	---	10	8	---	10	10
Control 2W-2	4.0	32.0	22.0	7.1	---	---	---	---	10	8	---	10	10
Control 2W-3	4.0	29.0	22.0	8.3	---	---	---	---	10	8	---	10	10
Control 2W-4	4.2	28.0	21.0	5.7	---	---	---	---	10	8	---	10	10
Average:	4.0	29.8	21.5	7.0	---	72.1	23.5	---	10	8	---	10	10
Control 2W (QUV avg.)	4.0	35.0	---	---	11.0	---	---	31.4	---	---	5	---	---
3W-1	6.6	46.0	40.0	22.0	---	---	---	---	10	10	---	10	10
3W-2	6.6	45.0	43.0	37.6	---	---	---	---	10	10	---	10	10
3W-3	6.5	41.0	46.0	16.5	---	---	---	---	10	10	---	10	10
3W-4	6.3	47.0	43.0	28.8	---	---	---	---	10	10	---	10	10
Average:	6.5	44.8	43.0	26.2	---	96.0	58.5	---	10	10	---	10	10
3W (QUV avg.):	5.9	56.5	---	---	11.0	---	---	19.5	---	---	8	---	---
4W-1	6.0	5.0	8.0	5.4	---	---	---	---	10	10	---	10	10
4W-2	5.7	6.0	8.0	4.6	---	---	---	---	10	10	---	10	10
4W-3	5.5	5.0	7.0	5.0	---	---	---	---	10	10	---	10	10
4W-4	5.7	5.0	7.0	4.4	---	---	---	---	10	10	---	10	10
Average:	5.7	5.3	7.5	4.9	---	141.5	92.5	---	10	10	---	10	10
4W (QUV avg.):	5.9	5.5	---	---	3.0	---	---	54.5	---	---	6	---	---
5W-1	5.5	41.0	42.0	32.3	---	---	---	---	10	8	---	10	10
5W-2	5.6	46.0	45.0	43.0	---	---	---	---	10	10	---	10	10
5W-3	6.0	52.0	45.0	28.6	---	---	---	---	10	8	---	10	10
5W-4	5.5	40.0	39.0	25.8	---	---	---	---	10	10	---	10	10
Average:	5.7	44.8	42.8	32.4	---	95.5	72.3	---	10	9	---	10	10
5W (QUV avg.):	6.0	51.0	---	---	12.0	---	---	23.5	---	---	8	---	---
6W-1	6.2	26.0	22.0	8.4	---	---	---	---	10	8	---	10	10
6W-2	6.1	32.0	22.0	6.4	---	---	---	---	10	8	---	10	10
6W-3	5.7	30.0	21.0	5.6	---	---	---	---	10	8	---	10	10
6W-4	5.6	21.0	19.0	6.7	---	---	---	---	10	8	---	10	10
Average:	5.9	27.3	21.0	6.8	---	76.9	24.9	---	10	8	---	10	10
6W (QUV avg.):	5.9	29.5	---	---	10.5	---	---	35.6	---	---	8	---	---

Table 5W. - Exterior exposure test - gloss, chalking, and thermal shock - 1 and 2 years exposure versus QUV accelerated weathering test - continued.

System No. Panel No.	Avg. DFT (mils)	Average gloss (60°)[1]			Avg. gloss (60°) QUV (3,000 hr)	Average gloss retained %			Chalk rating[2]			Thermal shock, cycles w/o failure (EE[3] panels only)[4]	
		Initial	1 year	2 years		1 year	2 years	QUV (3,000 hr)	1 year	2 years	QUV (3,000 hr)	1 year	2 years
7W-1	5.1	27.0	9.0	2.7	---	---	---	---	10	8	---	10	10
7W-2	5.0	26.0	12.0	2.6	---	---	---	---	10	8	---	10	10
7W-3	4.9	27.0	9.0	2.8	---	---	---	---	10	7	---	10	10
7W-4	5.2	27.0	12.0	2.8	---	---	---	---	10	7	---	10	10
Average:	5.1	26.8	10.5	2.7	---	39.2	10.1	---	10	7.5	---	10	10
7W (QUV avg.):	5.7	27.0	---	---	4.5	---	---	16.7	---	---	4	---	---
8W-1	5.7	31.0	10.0	2.8	---	---	---	---	10	7	---	10	10
8W-2	5.1	30.0	9.0	2.8	---	---	---	---	10	7	---	10	10
8W-3	5.1	29.0	17.0	3.5	---	---	---	---	10	7	---	10	10
8W-4	5.6	28.0	14.0	2.6	---	---	---	---	10	7	---	10	10
Average:	5.4	29.5	12.5	2.9	---	42.4	9.8	---	10	7	---	10	10
8W (QUV avg.):	6.0	27.0	---	---	3.5	---	---	13.0	---	---	4	---	---
9W-1	4.0	48.0	54.0	22.5	---	---	---	---	10	10	---	10	10
9W-2	4.7	58.0	56.0	47.2	---	---	---	---	10	10	---	10	10
9W-3	4.4	50.0	43.0	48.6	---	---	---	---	10	10	---	10	10
9W-4	4.7	52.0	56.0	18.1	---	---	---	---	10	10	---	10	10
Average:	4.5	52.0	52.3	34.1	---	100.6	65.6	---	10	10	---	10	10
9W (QUV avg.):	4.2	50.5	---	---	12.0	---	---	23.8	---	---	9	---	---
10W-1	4.1	48.0	52.0	19.7	---	---	---	---	10	10	---	10	10
10W-2	4.5	44.0	48.0	20.6	---	---	---	---	10	10	---	10	10
10W-3	4.5	46.0	49.0	18.0	---	---	---	---	10	10	---	10	10
10W-4	4.4	46.0	48.0	19.6	---	---	---	---	10	10	---	10	10
Average:	4.0	46.0	49.3	19.5	---	107.2	42.4	---	10	10	---	10	10
10W (QUV avg.):	4.6	46.0	---	---	16.5	---	---	35.9	---	---	10	---	---
11W-1	3.6	31.0	35.0	5.1	---	---	---	---	10	8	---	10	10
11W-2	3.9	31.0	34.0	4.9	---	---	---	---	10	8	---	10	10
11W-3	3.9	28.0	29.0	5.8	---	---	---	---	10	8	---	10	10
11W-4	3.0	29.0	32.0	4.6	---	---	---	---	10	8	---	10	10
Average:	3.6	29.8	32.5	5.1	---	109.1	17.1	---	10	8	---	10	10
11W (QUV avg.):	3.8	29.5	---	---	4.5	---	---	15.3	---	---	8	---	---
12W-1	4.6	6.0	10.0	3.7	---	---	---	---	10	10	---	10	10
12W-2	5.0	6.0	10.0	6.1	---	---	---	---	10	10	---	10	10
12W-3	4.6	6.0	10.0	3.9	---	---	---	---	10	8	---	10	10
12W-4	4.5	5.0	9.0	4.5	---	---	---	---	10	8	---	10	10
Average:	4.7	5.8	9.8	4.6	---	169.0	97.9	---	10	9	---	10	10
12W (QUV avg.):	4.5	5.0	---	---	3.0	---	---	60.0	---	---	6	---	---

Table 5W. - Exterior exposure test - gloss, chalking, and thermal shock - 1 and 2 years exposure versus QUV accelerated weathering test - continued.

System No. Panel No.	Avg. DFT (mils)	Average gloss (60°)[1]			Avg. gloss (60°) QUV (3,000 hr)	Average gloss retained %			Chalk rating[2]			Thermal shock, cycles w/o failure (EE[3] panels only)[4]	
		Initial	1 year	2 years		1 year	2 years	QUV (3,000 hr)	1 year	2 years	QUV (3,000 hr)	1 year	2 years
13W-1	9.2	11.0	3.0	0.9	---	---	---	---	6	7	---	10	10
13W-2	9.9	8.0	3.0	0.9	---	---	---	---	6	7	---	10	10
13W-3	10.4	7.0	3.0	0.9	---	---	---	---	6	7	---	10	10
13W-4	10.8	6.0	3.0	0.9	---	---	---	---	6	7	---	10	10
Average:	10.1	8.0	3.0	0.9	---	37.5	11.3	---	6	7	---	10	10
13W (QUV avg.):	10.6	15.0	---	---	2.0	---	---	13.3	---	---	2	---	---
14W-1	9.6	29.8	5.1	3.1	---	---	---	---	10	8	---	10	10
14W-2	8.6	30.6	4.6	3.4	---	---	---	---	10	8	---	10	10
14W-3	8.9	28.1	6.5	3.3	---	---	---	---	10	8	---	10	10
14W-4	9.5	30.3	4.7	3.3	---	---	---	---	10	8	---	10	10
Average:	9.2	29.7	5.2	3.3	---	17.5	11.1	---	10	8	---	10	10
14W (QUV avg.):	8.6	27.5	---	---	2.5	---	---	9.1	---	---	6	---	---
15W-1	6.2	73.0	76.4	54.6	---	---	---	---	10	10	---	10	10
15W-2	6.0	72.1	84.7	45.1	---	---	---	---	10	8	---	10	10
15W-3	5.0	70.7	81.4	44.0	---	---	---	---	10	10	---	10	10
15W-4	6.2	67.6	70.6	48.3	---	---	---	---	10	10	---	10	10
Average:	5.9	70.9	78.3	48.0	---	110.4	67.7	---	10	9.5	---	10	10
15W (QUV avg.):	5.8	72.1	---	---	18.2	---	---	19.8	---	---	5	---	---
16W-1	6.1	37.9	44.8	38.3	---	---	---	---	10	10	---	10	10
16W-2	5.5	39.5	37.7	35.5	---	---	---	---	10	10	---	10	10
16W-3	5.6	31.4	34.6	34.3	---	---	---	---	10	10	---	10	10
16W-4	5.8	37.5	43.5	26.8	---	---	---	---	10	10	---	10	10
Average:	5.8	36.6	40.2	33.7	---	109.8	92.1	---	10	10	---	10	10
16W (QUV avg.):	4.5	42.4	---	---	11.0	---	---	25.9	---	---	9	---	---
17W-1	6.0	80.2	32.3	8.5	---	---	---	---	10	8	---	10	10
17W-2	6.1	79.1	22.5	9.1	---	---	---	---	10	8	---	10	10
17W-3	6.2	82.0	23.7	17.7	---	---	---	---	10	8	---	10	10
17W-4	5.9	81.1	28.0	21.6	---	---	---	---	10	8	---	10	10
Average:	6.1	80.6	26.6	14.2	---	33.0	17.6	---	10	8	---	10	10
17W (QUV avg.):	4.5	66.8	---	---	6.2	---	---	9.3	---	---	8	---	---

[1] Measured at 60° from the vertical.
[2] 10 = No chalking, 0 = very heavy chalking.
[3] EE = Exterior exposure.
[4] A rating of 10 = no damage from thermal shock test.

Table 6W. - Exterior exposure (EE) test - color data (averages of four panels)[1] versus QUV accelerated weathering test.

System No.	Illuminant	EE color data (initial)			EE color change (1 year)				EE color change (2 years)				QUV (3,000 hr)	Visual color initial
		L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	ΔE^*_{ab}	
Control 1W	C	93.90	-7.64	8.64	-1.60	0.90	-1.69	2.54	-1.09	6.89	-4.35	8.26	0.47	White
Control 1W	D65	93.98	-1.45	3.94	-1.63	0.79	-1.57	2.45	-1.39	0.84	0.41	1.69	0.58	White
Control 2W	C	91.19	-7.61	5.61	-1.54	0.69	-1.03	2.09	-1.71	6.65	-3.98	7.95	0.62	White
Control 2W	D65	91.20	-1.62	1.00	-1.47	0.58	-0.99	1.96	-1.25	0.68	0.67	1.60	0.77	White
3W	C	92.29	-7.64	8.59	-2.69	0.57	0.21	2.77	-2.67	6.47	-3.02	7.66	0.50	White
3W	D65	92.27	-1.62	4.01	-2.63	0.48	0.37	2.72	-2.17	0.61	1.64	2.82	0.43	White
4W	C	92.76	-7.14	6.14	-3.20	0.50	1.00	3.39	-3.19	6.47	-1.95	7.53	0.58	White
4W	D65	92.90	-1.11	1.55	-3.28	0.40	1.08	3.47	-3.01	0.56	2.70	4.12	0.51	White
5W	C	92.62	-7.59	8.92	-2.89	0.58	0.06	2.96	-2.71	6.48	-3.00	7.75	0.42	White
5W	D65	92.68	-1.50	4.30	-2.89	0.39	0.23	2.93	-2.48	0.57	1.69	3.10	0.44	White
6W	C	91.93	-7.73	9.00	-0.73	0.96	-3.07	3.33	-1.55	6.93	-5.61	9.08	0.95	White
6W	D65	92.26	-1.62	4.25	-1.04	0.84	-2.87	3.32	-1.33	0.89	-0.88	1.92	0.96	White
7W	C	92.58	-7.68	8.06	-1.63	0.59	0.22	1.75	-2.22	6.40	-1.52	6.96	3.91	White
7W	D65	92.75	-1.61	3.43	-1.89	0.54	0.44	2.02	-2.05	0.52	3.18	3.83	3.87	White
8W	C	92.89	-7.52	7.38	-1.51	0.34	0.98	1.85	-2.63	6.31	-0.93	6.90	3.39	White
8W	D65	92.89	-1.41	2.88	-1.40	0.23	0.93	1.71	-2.25	0.41	3.58	4.26	3.62	White
9W	C	92.63	-7.62	8.87	-2.66	0.53	0.15	2.73	-2.94	6.51	-2.63	7.79	0.47	White
9W	D65	92.71	-1.52	4.33	-2.65	0.38	0.25	2.70	-2.74	0.57	2.00	3.47	0.50	White
10W	C	96.08	-7.61	5.67	-2.71	0.88	-0.33	2.87	-3.94	6.99	-2.76	8.50	0.68	White
10W	D65	96.00	-1.33	0.81	-2.59	0.71	-0.15	2.70	-3.45	0.82	2.15	4.15	0.58	White
11W	C	54.51	-4.94	-2.61	-0.95	0.20	-0.08	1.00	1.24	4.04	-2.55	4.96	4.35	Dark gray
11W	D65	54.60	-1.06	-5.84	-0.92	0.15	-0.01	0.95	1.51	-0.04	0.71	1.73	4.55	Dark gray
12W	C	92.51	-7.38	6.02	-2.82	0.65	0.79	3.00	-3.37	6.58	-1.96	7.66	0.52	White
12W	D65	92.59	-1.39	1.35	-2.82	0.56	-0.94	3.03	-3.03	0.72	2.79	4.19	0.55	White
13W	C	57.97	-16.39	17.04	3.57	4.39	-2.10	6.04	3.58	9.47	-4.94	11.34	12.92	Green
13W	D65	58.07	-12.42	14.24	3.56	4.71	-2.30	6.22	3.64	5.78	-2.02	7.13	13.38	Green
14W	C	92.83	-7.32	7.32	-2.17	6.06	-2.90	7.09	-1.04	6.25	-2.65	6.88	3.74	White
14W	D65	92.94	-1.23	2.71	-2.30	0.03	1.72	2.88	-0.69	0.30	1.95	2.10	3.94	White

Table 6W. - Exterior exposure (EE) test - color data (averages of four panels)[1] vs. QUV accelerated weathering test - Continued.

System No.	Illuminant	EE color data (initial)			EE color change (1 year)				EE color change (2 years)				QUV (3,000 hr)	Visual color initial
		L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	ΔL^*	Δa^*	Δb^*	ΔE^*_{ab}	ΔE^*_{ab}	
15W	C	94.15	-7.09	5.73	-1.74	6.24	-3.21	7.24	-1.00	6.35	-3.39	7.27	0.91	White
15W	D65	94.28	-0.95	1.00	-1.47	0.16	1.62	2.21	-0.73	0.28	1.37	1.59	0.91	White
16W	C	97.18	-7.06	4.78	-3.84	6.59	-3.30	8.31	-2.46	6.78	-3.35	7.96	0.70	White
16W	D65	97.21	-0.67	-0.14	-3.90	0.19	-1.76	4.29	-2.05	0.45	1.58	2.62	0.83	White
17W	C	92.98	-6.67	3.49	-2.54	5.82	-2.03	6.68	-0.22	5.98	-2.48	6.48	1.49	White
17W	D65	93.05	-0.69	-1.22	-2.55	-0.27	2.59	3.65	0.11	-0.07	2.26	2.27	1.54	White

[1] See Note 1, table 4W, for explanation of color shift directions and color difference formulas.

Table 7W. - Immersion tests.

System No. Panel No.	Saltwater immersion: Average DFT (mils)	Initial blistering (hours)[3]	Total hours completed	Blister size and frequency (completion)[1]	Color difference (after immersion, avg. of 1 and 2)		Freshwater (deionized) immersion: Average DFT (mils)	Initial blistering (hours)	Total hours completed	Blister size and frequency (completion)	Color difference (after immersion, avg. of 1 and 2)	
					Ill. C	Ill. D65					Ill. C	Ill. D65
13W-1	10.3	---	5,626	---	1.89	2.10	10.6	---	7,054	---	12.48	12.67
13W-2	10.6	---	5,626	---	---	---	10.2	---	7,054	---	---	---
Average or comments	10.5	---	5,626	---	---	---	10.4	---	7,054	---	---	---
14W-1[4]	11.7	161.4	3,080	Dense Nos. 2 and 4	C.N.B.T.	C.N.B.T.[2]	9.9	161.4	3,477	Dense (mixed Nos.)	C.N.B.T.	C.N.B.T.
14W-2	9.0	161.4	3,080	Dense Nos. 2 and 4	C.N.B.T.	C.N.B.T.	9.0	161.4	3,477	Dense (mixed Nos.)	C.N.B.T.	C.N.B.T.
Average or comments	10.4	161.4	3,080	Dense No. 2 on backs	C.N.B.T.	C.N.B.T.	9.5	161.4	3,477	Dense Nos. 4 and 10 on backs	C.N.B.T.	C.N.B.T.

1 *Pictorial Standards of Coatings Defects* and ASTM D 714-87. The largest number refers to the smallest blister on a scale of 2 - 8 (2 - larger, 10 - small).
2 C.N.B.T. = Could not be tested. The panels were too blistered to test for color.
3 The number of hours recorded are the number of hours of exposure as of the time the panels were examined. The exact number of hours of exposure before blistering took place are unknown. However, in no instance would the number of hours be less than the recorded number of hours by more than 1 week's exposure time, about 164 to 168 hours.
4 System No. 14W is not an immersion coating. It acted as the control coating for system No. 13W.

Table 8W. - Summary of all tests - replicate panels averaged[1].

System No.	Generic type topcoat color	Avg. DFT (mils)	Application properties	Adhesion	1-Inch Mandrel bend test	Early rust resistance (primer only)	QUV % gloss retention 3,000 hr	QUV chalk rating 3,000 hr	QUV color difference (Ill. C) 3,000 hr	EE % gloss retention[4]		EE chalk rating		Thermal shock cycles w/o failure		EE color difference (Ill. C)		Immersion (systems Nos. 13W and 14W only)
										1 year	2 years	1 year	2 years	1 year	2 years	1 year	2 years	
1W (control)	Alkyd and silicone alkyd - white	4.1	Satisfactory	4B	NC	No R or B	(47.5) 26.3[2]	8	0.47	(41.5) 61.0[2]	18.1	10	8	10	10	2.54	8.26	N/A
2W (control)	Alkyd and silicone alkyd - white	4.1	Satisfactory	2B	Cracked	N/A	(35.0) 31.4	5	0.62	(29.8) 72.0	23.5	10	8	10	10	2.09	7.95	N/A
3W	Acrylic emulsion coating - white	6.1	Satisfactory	5B	NC	R&B	(56.5) 19.5	8	0.50	(44.8) 96.0	58.5	10	10	10	10	2.77	7.66	N/A
4W	Acrylic emulsion coating - white	5.7	Satisfactory	5B	NC	B	(5.5) 54.5	6	0.58	(5.3) 141.5	92.5	10	10	10	10	3.39	7.53	N/A
5W	Acrylic emulsion coating - white	5.8	Satisfactory	5B	NC	NT(4W)	(51.0) 23.5	8	0.42	(44.8) 95.5	72.3	10	9	10	10	2.96	7.75	N/A
6W	Acrylic emulsion/ silicone alkyd - white	5.9	Satisfactory	4B	NC	NT(3W)	(29.5) 35.6	8	0.95	(27.3) 76.9	24.9	10	8	10	10	3.33	9.08	N/A
7W	Waterborne catalyzed epoxy - white	5.2	Satisfactory	5B	NC	R&B	(27.0) 16.7	4	3.91	(26.8) 39.2	10.1	10	7.5	10	10	1.75	6.96	N/A
8W	Acrylic emulsion/ waterborne catalyzed epoxy - white	5.1	Satisfactory	5B	NC	NT(3W)	(27.0) 13.0	4	3.39	(29.5) 42.4	9.8	10	7	10	10	1.85	6.90	N/A

Table 8W. - Summary of all tests - replicate panels averaged[1] - continued.

System No.	Generic type topcoat color	Avg. DFT (mils)	Application properties	Adhesion	1-Inch Mandrel bend test	Early rust resistance (primer only)	QUV % gloss retention 3,000 hr	QUV chalk rating 3,000 hr	QUV color difference (Ill. C) 3,000 hr	EE % gloss retention[4]		EE chalk rating		Thermal shock cycles w/o failure		EE color difference (Ill. C)		Immersion (systems Nos. 13W and 14W only)
										1 year	2 years	1 year	2 years	1 year	2 years	1 year	2 years	
9W	Inorganic zinc/acrylic emulsion - white	4.4	Satisfactory	4B	NC	No r or B	(50.5) 23.8	9	0.47	(52.0) 100.6	65.6	10	10	10	10	2.73	7.79	N/A
10W	Inorganic zinc/acrylic emulsion - white	4.3	Satisfactory	5B	NC	NT(9)	(46.0) 35.9	10	0.58	(46.0) 107.2	42.4	10	10	10	10	2.87	8.50	N/A
11W	Inorganic zinc/acrylic emulsion - dark gray	3.5	Satisfactory	4B	NC	NT(9)	(29.5)15.3	8	4.35	(29.8) 109.1	17.1	10	8	10	10	1.00	4.96	N/A
12W	Inorganic zinc/acrylic emulsion - white	4.6	Satisfactory	0B	NC	NT(9)	5.0) 60.0	6	0.52	(5.8) 169.0	97.9	10	9	10	10	3.00	7.66	N/A
13W	Waterborne catalyzed epoxy for immersion - green	10.6	Satisfactory	200 psi (1,379 kPa)	NC	R&B	(15.0) 13.3	2	12.92	(8.0) 37.5	11.3	6	7	10	10	6.04	11.34	Passed 3,000 hr in saltwater and freshwater immersion
14W	Waterborne catalyzed epoxy - white	7.7	Satisfactory	5B	Sl. crack along bend	No R or B	(27.5) 9.1	6	3.74	(29.7) 17.5	11.1	10	8	10	10	7.09	6.88	Failed immersion tests
15W	Acrylic emulsion coating - white	5.2	Satisfactory	5B	NC	No R or B	(72.1) 19.8	5	0.91	(70.9) 110.4	67.7	10	9.5	10	10	7.24	7.27	N/A

Table 8W. - Summary of all tests - replicate panels averaged[1] - continued.

System No.	Generic type topcoat color	Avg. DFT (mils)	Application properties	Adhesion	1-Inch Mandrel bend test	Early rust resistance (primer only)	QUV % gloss retention 3,000 hr	QUV chalk rating 3,000 hr	QUV color difference (Ill. C) 3,000 hr	EE % gloss retention[4]		EE chalk rating		Thermal shock cycles w/o failure		EE color difference (Ill. C)		Immersion (systems Nos. 13W and 14W only)
										1 year	2 years	1 year	2 years	1 year	2 years	1 year	2 years	
16W	Acrylic emulsion coating (SG) - white[3]	4.9	Satisfactory	5B	NC	No R or B	(42.4) 25.9	9	0.70	(36.6) 109.8	92.1	10	10	10	10	8.31	7.96	N/A
17W	Acrylic emulsion coating (G) - white[3]	5.1	Satisfactory	5B	NC	NT(16W)	(66.8) 9.3[2]	8	1.49	(80.6) 33.0	17.6	10	8	10	10	6.68	6.48	N/A

[1] See previous tables for explanation of abbreviations.
[2] Numbers in parentheses are the initial gloss readings.
[3] SG = Semigloss, G = gloss.
[4] EE = Exterior exposure.

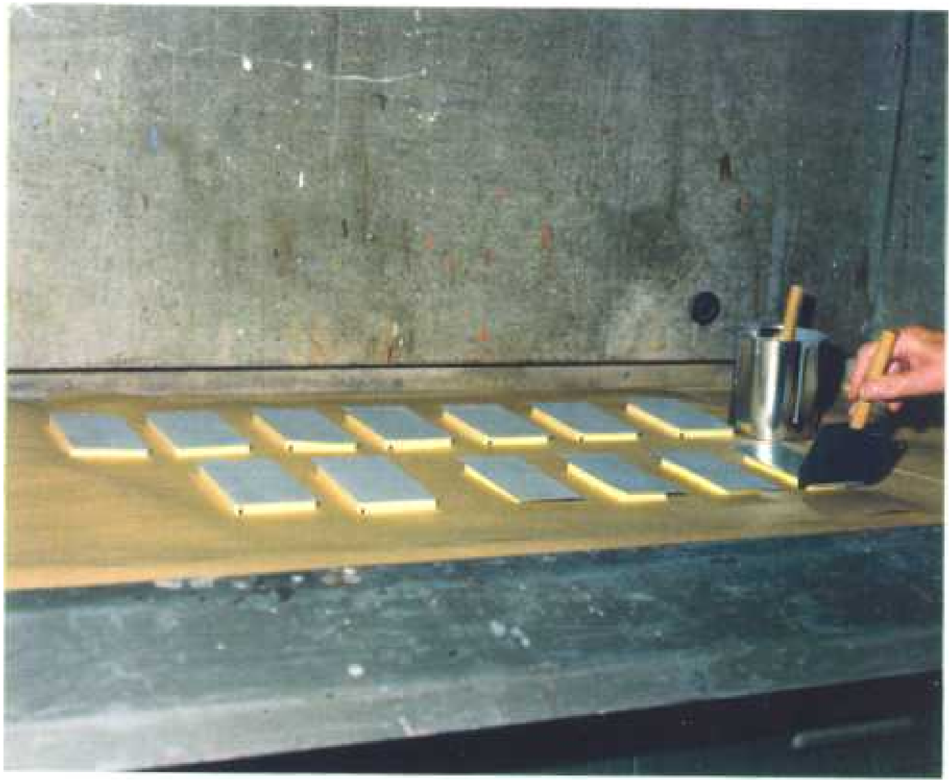
APPENDIX B

Figures

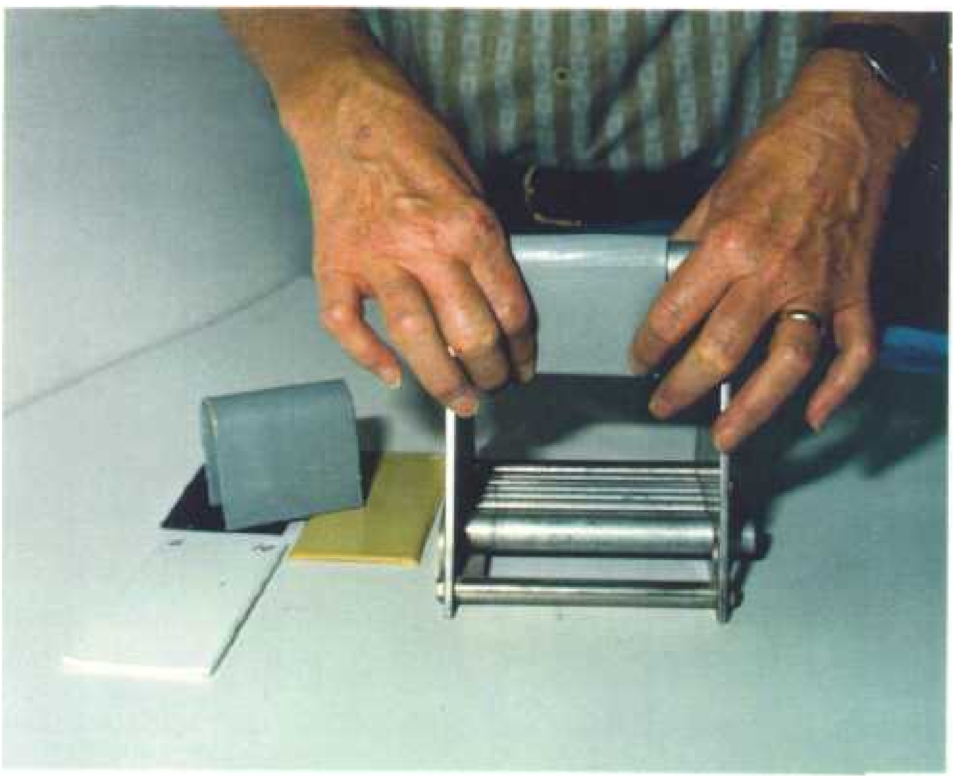
APPENDIX FIGURE 1

Pictures of Laboratory Equipment

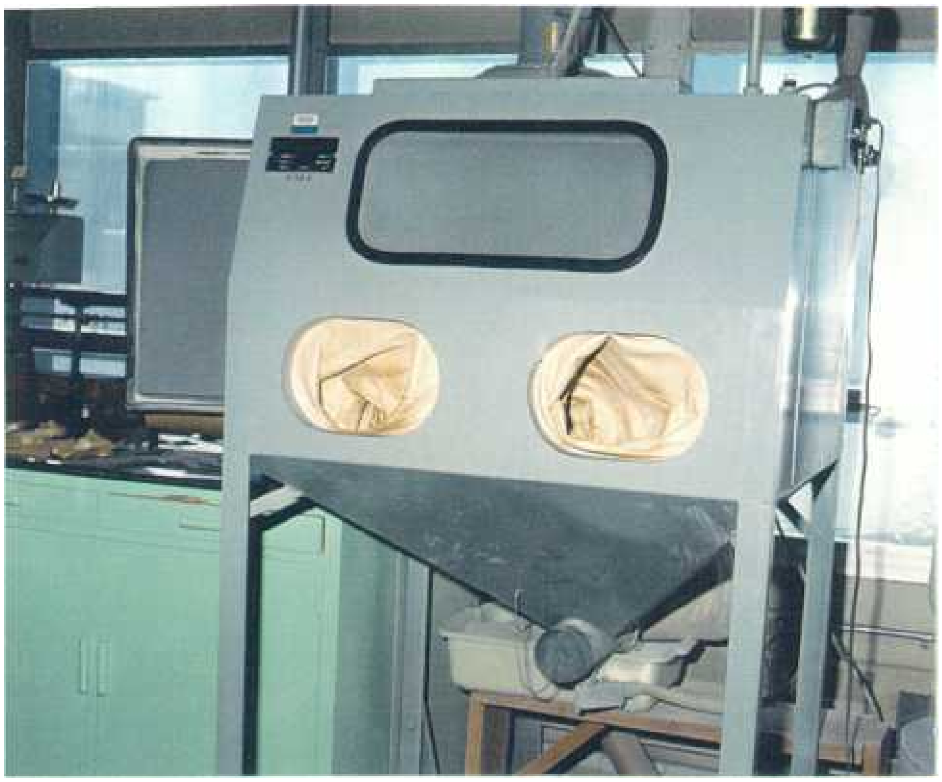
Page



Application of a coating system to the testing panels

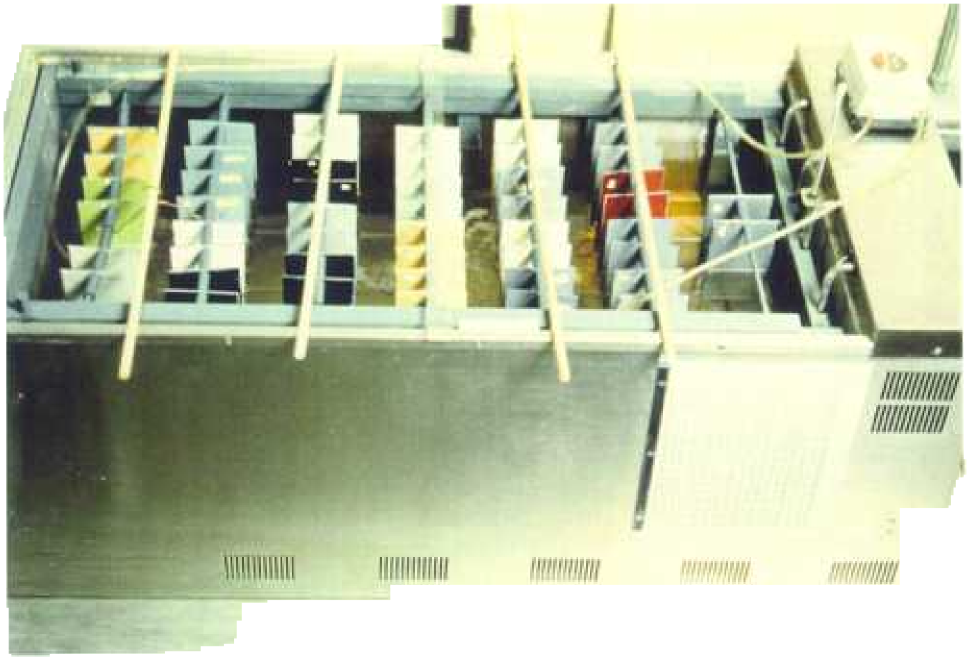


One-inch mandrel bend test.

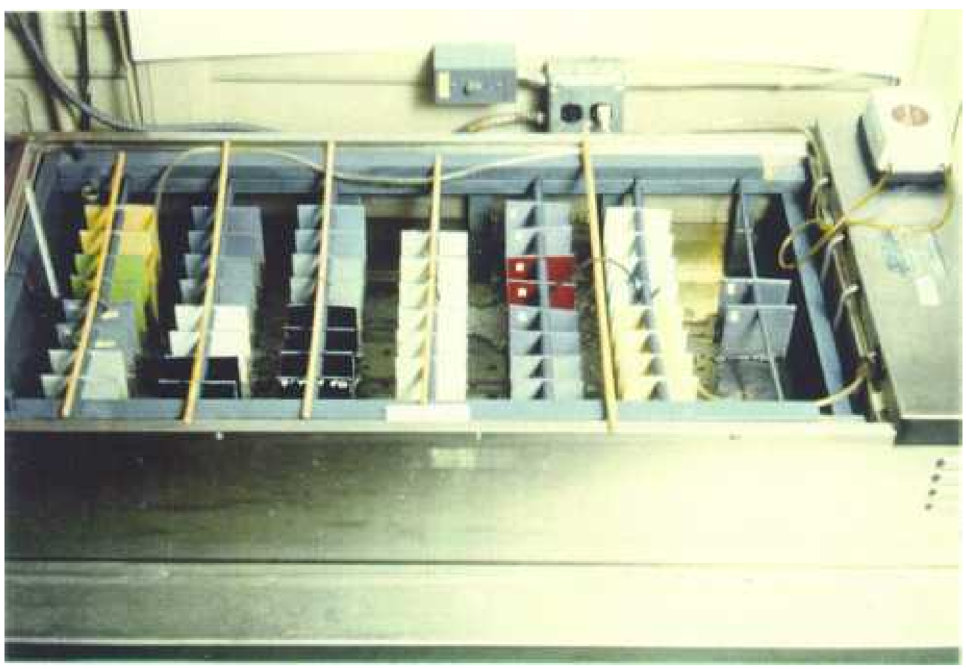


Inland UNI-BLASTER SB-7 media blasting cabinet.

Inside view of the media blasting cabinet - panel preparation.

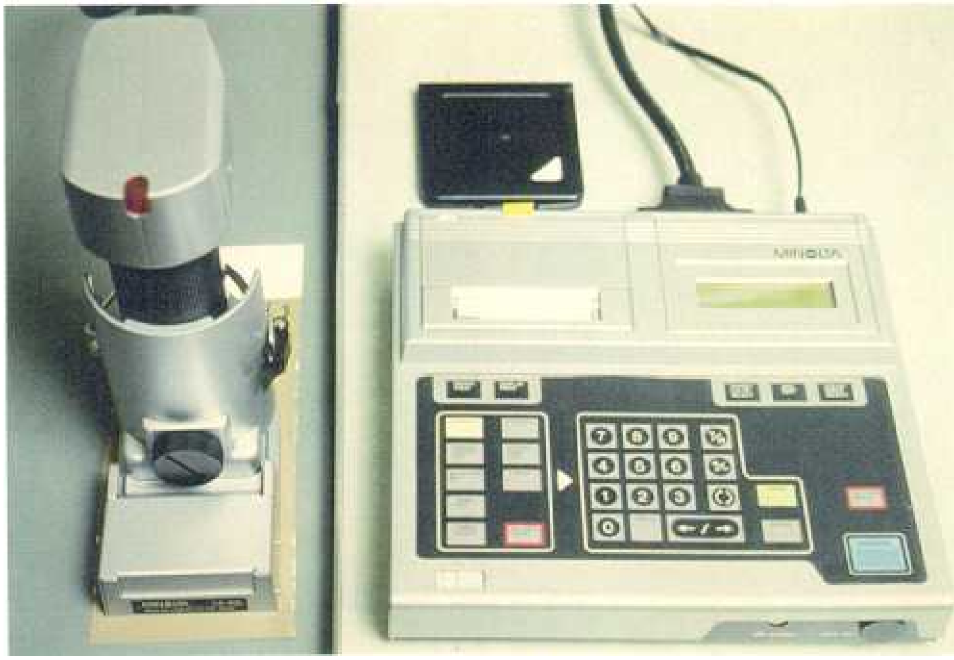


Saltwater immersion test.

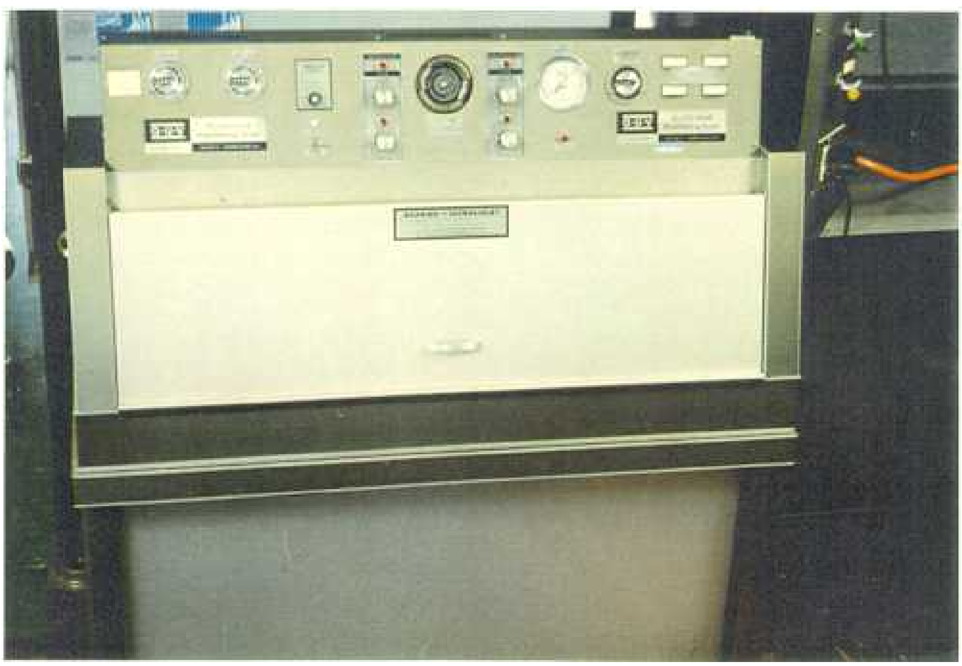


Freshwater immersion test.

Elcometer pull-off adhesion tester with accessories.



nolta CR-200b roma mete

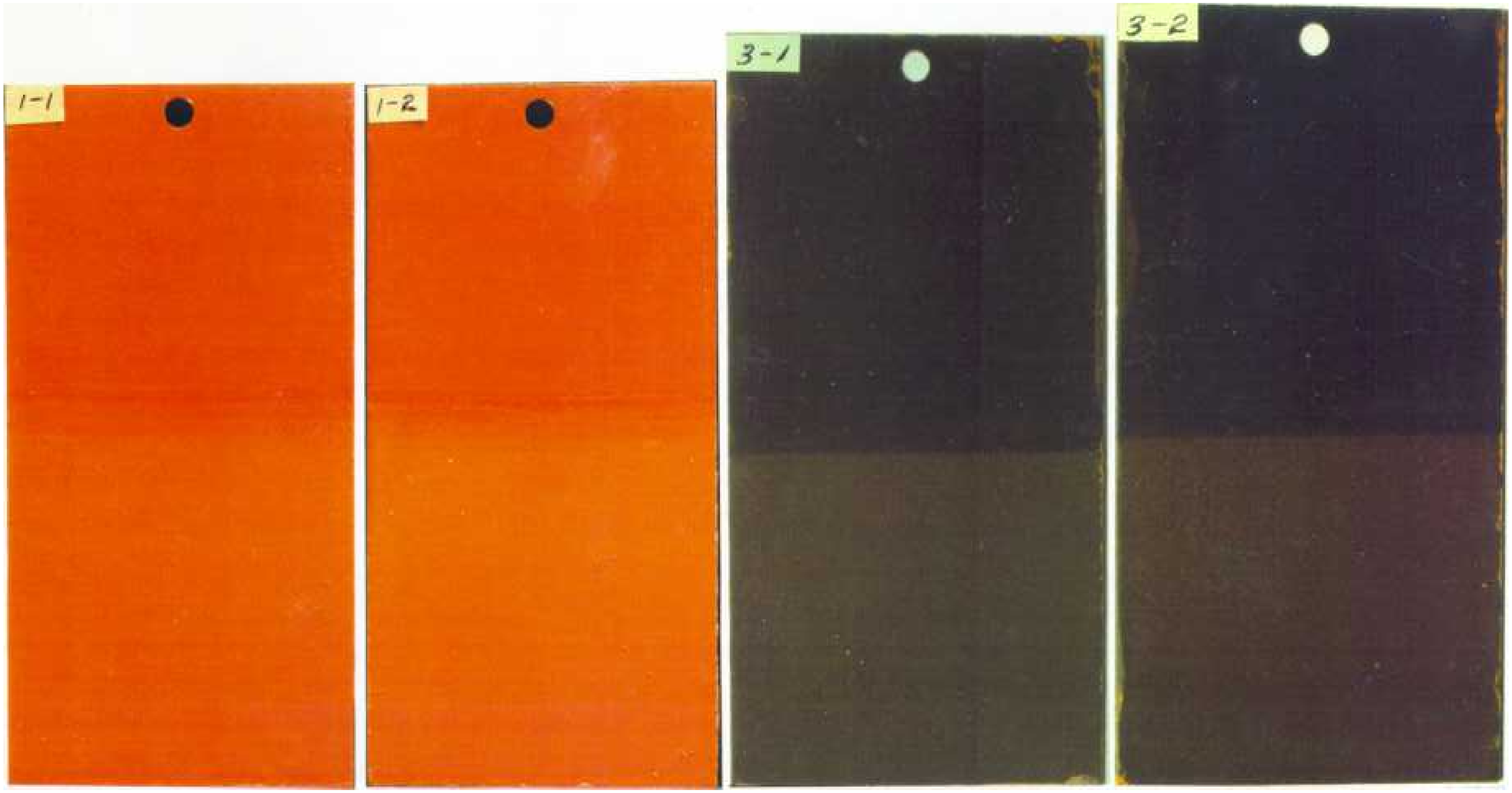


QUV accelerated eathering apparatus.

APPENDIX FIGURE 2

Typical Examples of Red Lead Replacement RLR Series Panels

Untopcoated Panels Following the Immersion Test



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Primer No. 3 - panel No. 1
untopcoated.

Primer No. 3 - panel No. 2
untopcoated.

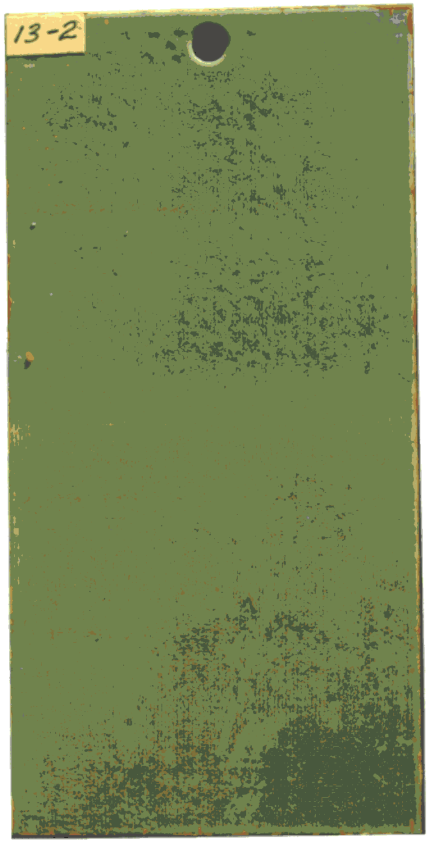
Note the relatively chalk free appearance.

Primer No. 4 - panel No.
untopcoated.

Primer No. 4 - panel No. 2
untopcoated.

Note the relatively heavy surface chalking on the panels.

Primer No. 1 - panel No. 1 - TT-E-490E topcoat.



Primer No. 1 - panel No. 2 - TT-E-490E topcoat.

Primer No. 2 - panel No. 1 TT-E-490E topcoat.

Primer No. 2 - panel No. 2 TT-E-490E topcoat.

Note absence of blisters compared to the previous primer No. 1 untopcoated immersion panels.

Note the large intercoat blister, plus many smaller blisters, compared to the previous primer No. 2 untopcoated immersion panels.

APPENDIX FIGURE 3

Typical Examples of Immersion X Series Panels

Panels Following QUV Exposure

Page

Panels Following Either FW (Freshwater) or SW (Saltwater) Exposure

Note absence of blisters on both the freshwater and saltwater immersion panels. The freshwater immersion panels typically showed heavier rusting compared to the typical saltwater immersion panels.

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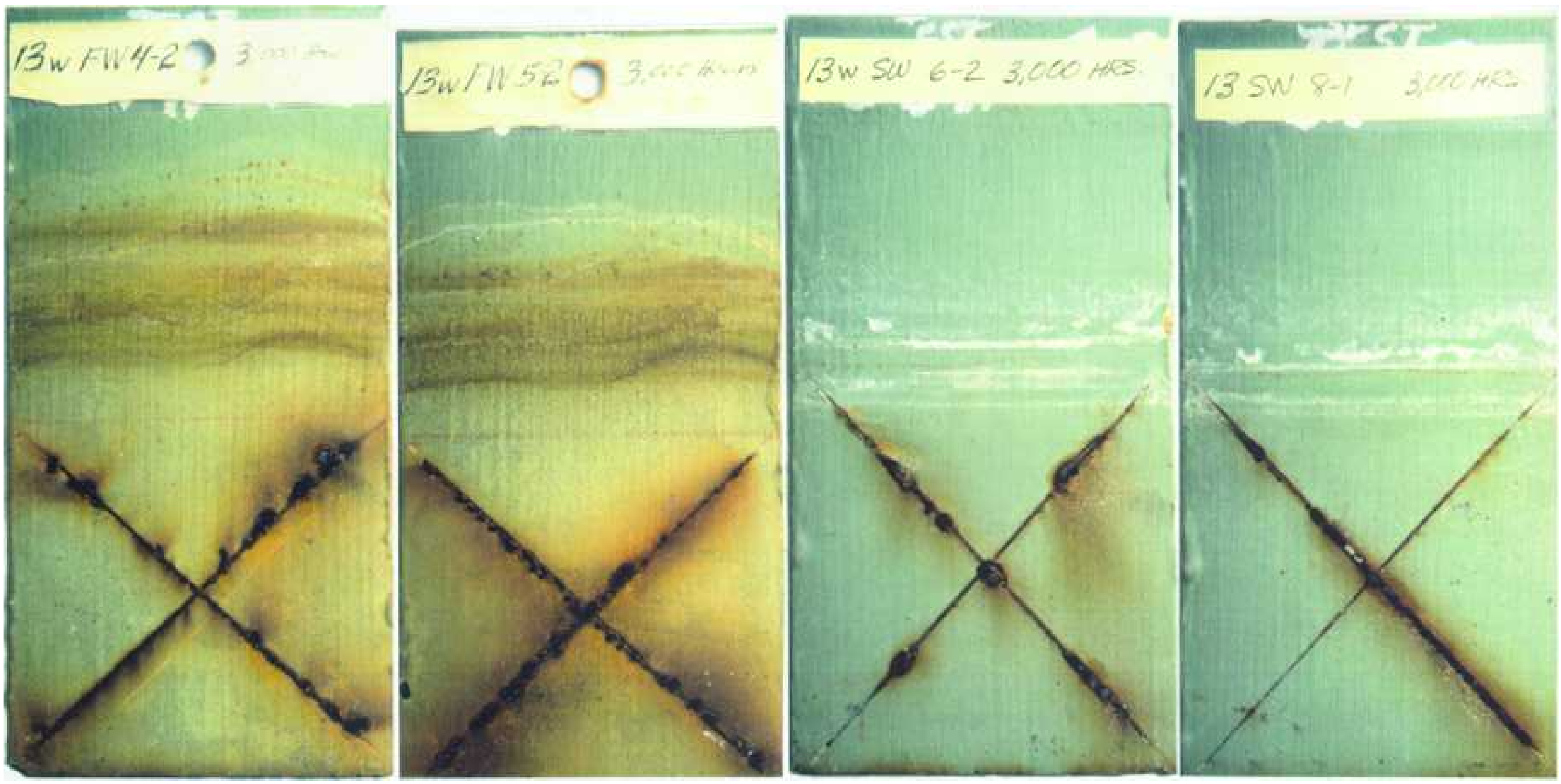


13W - FW panel No. 4-2.   13W - FW panel No. 5-2.   13W - SW panel No. 6-2.   13W - SW panel No. 8-1.

Note absence of blisters on both the freshwater and saltwater immersion panels. The freshwater immersion panels typicall showed heavier rusting compared to the typical immersion panels.

APPENDIX FIGURE 4

Typical Examples of Waterborne W Series Panels

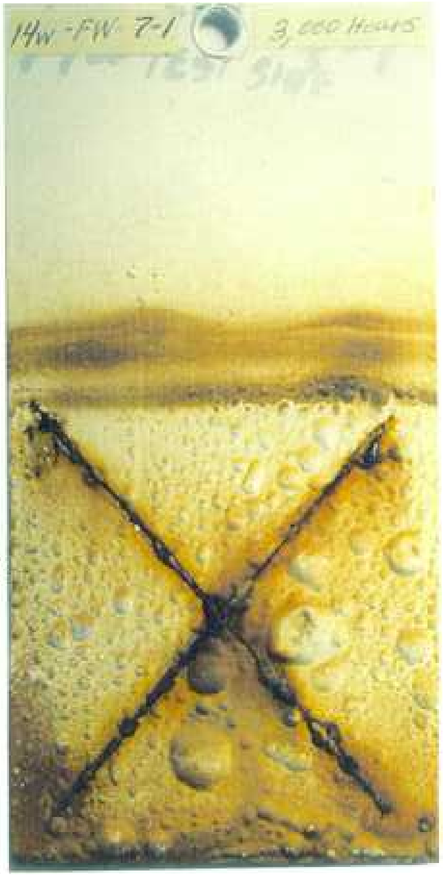
Panels Following Either FW (Freshwater) or SW (Saltwater) Immersion

Note heavy blistering which appeared after one week of immersion. The blistering even extended above the waterline. This conventional waterborne catalyzed epoxy is not normally used for immersion service. Compare this system after immersion against the 13W system shown on appendix figure 3, which had been immersed over 3,000 hours.

Panels Following QUV Exposure

Note surface chalking, but lack of blisters on the lower half of the panels.

Note the anticipated chalking, but the lack of blisters on the lower half of the panels. The spots on panel 1-1 are a result of mechanical damage, which occurred after the panels were removed from the test setup.



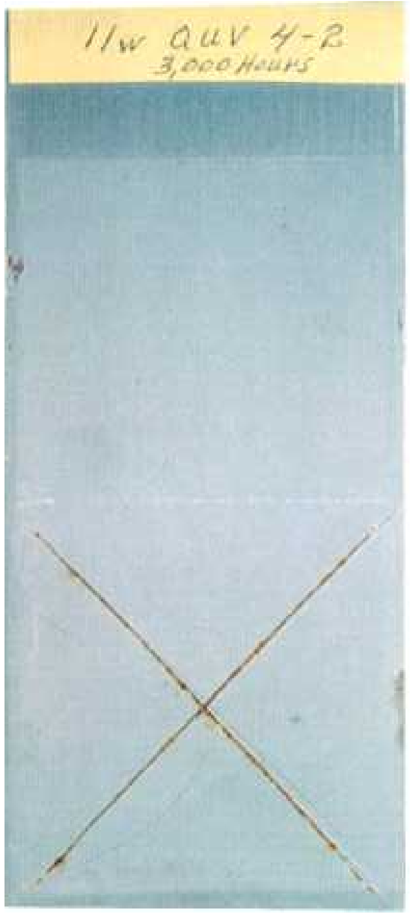
14W-FW panel No. 7-1.

14W-FW panel No. 8-1.

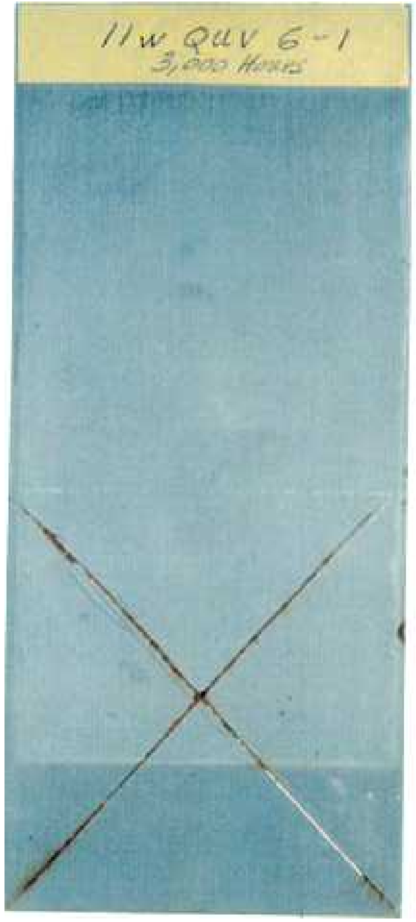
14W-SW panel No. 11-1

14W-SW panel No. 12-1

Note heavy blistering which appeared after one week of immersion. The blistering even extended above the waterline. This conventional waterborne catalyzed epoxy is not normally used for immersion service. Compare this system after immersion against the 13W system shown on appendix figure 3, which had been immersed over 3,000 hours.

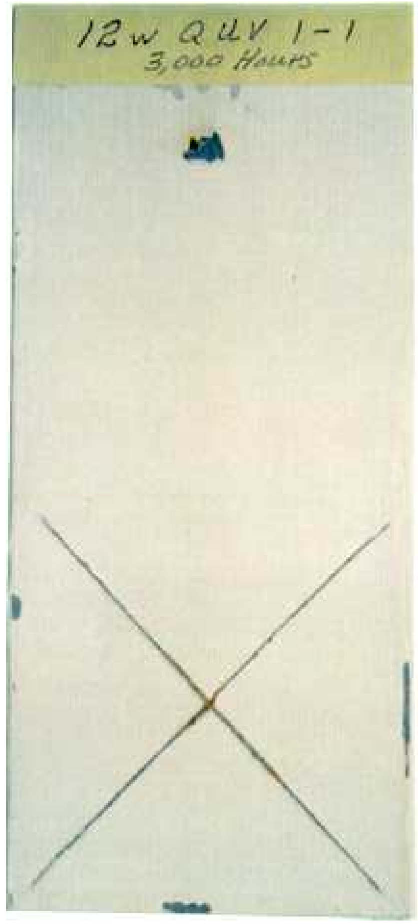


11W-QUV panel No. 4-2.



11W-QUV panel No. 6-

Note surface chalking, but lack of blisters on the lower half of the panels.



12W-QUV panel No. 1

12W-QUV panel No. 2-1

Note the anticipated chalking, but the lack of blisters on the lower half of the panels. The spots on panel No. 1-1 are a result of mechanical damage, which occurred after the panels were removed from the test setup.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.