Technical Report Documentation Page

1. REPORT No.
FHWA/CA/TL-88/04

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Structural Steel Coatings and Pretreatments for Use in Lieu of Blast Cleaning

5. REPORT DATE
June 1988

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Andrew Rogerson

8. PERFORMING ORGANIZATION REPORT No.
637326

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
E84TL17

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95814

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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17. KEYWORDS
Pretreatments, coatings, hand-cleaned steel, surface-tolerant, rust converters, structural steel, VOC-compliant

18. No. OF PAGES:
114

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1981-1988/88-04.pdf

20. FILE NAME
88-04.pdf

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

STRUCTURAL STEEL COATINGS AND PRETREATMENTS FOR USE IN LIEU OF BLAST CLEANING

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88-04

40-88

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. FHWA/CA/TL-88/04	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
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		6. PERFORMING ORGANIZATION CODE
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17. KEY WORDS Pretreatments, coatings, hand-cleaned steel, surface-tolerant, rust converters, structural steel, VOC-compliant	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Service, Springfield, VA 22161.

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified		

DS-TL-1242 (Rev.6/76)

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (1) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

ACKNOWLEDGEMENTS

The investigators would like to thank the editors of The Journal of Coatings Technology and American Paint and Coatings Journal for their cooperation in announcing the project within their publications so that a wider range of samples could be included in the project.

Special thanks are extended to the coating and raw material suppliers for their cooperation in providing technical information and samples of materials used in this project.

Acknowledgement should be given to:

Anne Spiesman formerly of the Transportation Laboratory who assisted with laboratory and field work.

Kristin King and Harold Hunt of the Transportation Laboratory who performed the bioassays used in this report.

Bob Warren of the Golden Gate Bridge and Transportation District who provided the test racks used for exposure beneath the Golden Gate Bridge.

Special acknowledgement should also be given to Frank Pacholl, Normand Moore and Dale Perry of Caltrans Office of Structures Maintenance and Investigations who cooperated in full-scale evaluations and implementation of the results of this study.

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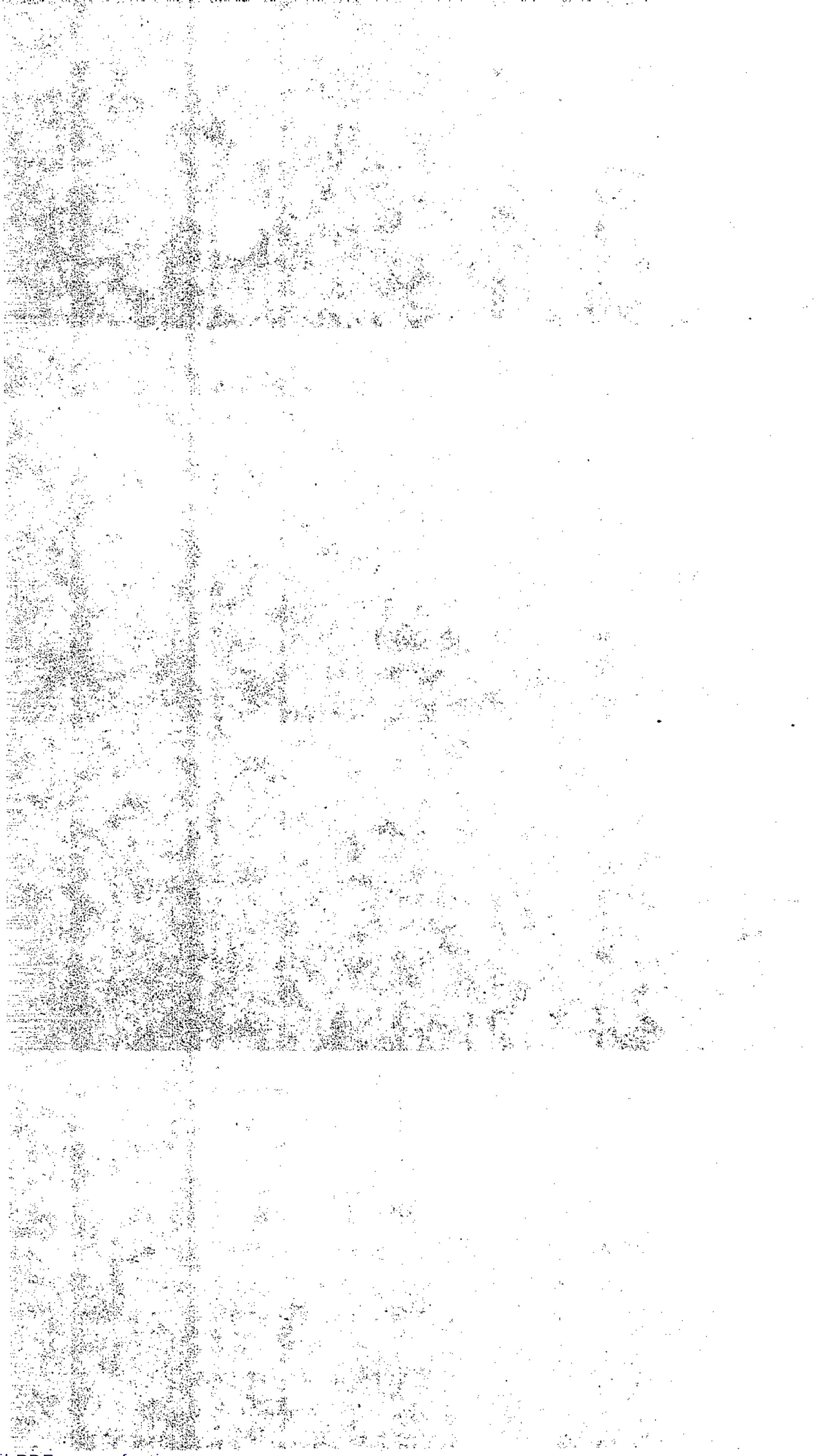

INTRODUCTION

Most coatings adhere to metal by means of physicochemical attraction which develops when the coating-to-metal distance is less than five angstroms. Because grains of dust and even monomolecular films of oil are considerably thicker than five angstroms, their presence can greatly reduce or nullify adhesion (1). If surface rust is present, either from incomplete removal or from reformation following removal, the net result will be the same; interference with the coating-to-metal bond. Consequently, surface preparation is the single most important factor in coating performance.

When a paint system no longer provides adequate protection to a structure, Caltrans' preferred method of preparing the structure for repainting has been dry, abrasive-blast cleaning. Until recently, little concern had been directed toward the ultimate fate of the abrasive-blasting residues removed from the structures, and abrasive-blasting containment had been haphazard and inconsistent. Increasingly, environmental protection laws are impacting structural steel painting operations. The California Code of Regulations includes barium, chromium, lead, zinc and their compounds in a listing of persistent and bioaccumulative toxic substances for which there is a soluble threshold limit concentration (STLC) and a total threshold limit concentration (TTLC) (2). Waste containing these compounds in excess of either the extractable limit or the total limit are required to be treated as hazardous waste. They cannot be indiscriminately discharged to the environment, but must be contained, collected, and disposed of according to a rigorous set of regulations.

The net effect of these regulations has been to drastically increase the cost to repaint a structure. In the past, bids to repaint structures have typically been below estimates, but most recent bids have been thirty to forty percent over cost estimates with the bulk of the increase attributable to containment and disposal of blasting debris (3).

Prior to 1949, the standard primer system used in California for the protection of structural steel was a red lead-linseed oil system. Since then, a number of other primer systems have been used including quick dry red lead primers, basic lead silico-chromate primers, zinc chromate primers, inorganic and organic zinc-rich primers and latex systems containing barium, zinc or chromate type compounds. These systems have generally provided good protection to structural steel with life spans exceeding forty years for some structures located in mild exposure areas (4). There are many products on the market which the manufacturers claim can provide protection to hand-cleaned steel. If the claims for the efficacy of these systems were true, their use would provide several benefits including saving the costs of abrasive blasting and containment and elimination of the discharge of toxic metals to the environment.

This project involved a solicitation through industry journals for manufacturers of specialty coatings designed for application to rusty, hand-cleaned steel to submit samples for evaluation. It was requested that submittals be restricted to materials containing no more than 250 grams of volatile organic compounds (VOC) per liter excluding water and exempt solvents. This was to insure that materials would comply with the most stringent air pollution control regulations being considered within the state.

Project samples were assigned numbers and categorized by their purported mode of action. They were brush applied to various test panels, subjected to accelerated laboratory tests and exposed on a test rack beneath the Golden Gate Bridge in San Francisco. Panels were rated according to American Society for Testing and Materials (ASTM) visual and photographic standards. Performance was compared with a primer system in use by Caltrans which was applied to the same types of surfaces. The primary objective was to verify manufacturers claims that their products could be applied to hand-cleaned surfaces with little or no compromise in performance. Secondarily, the objective was to compare performance with a coating system currently being used by Caltrans.

CONCLUSIONS

Abrasive blasting was the most effective procedure for preparing steel for painting. The data show that ratings for abrasive-blasted panels were generally the highest, particularly under actual field exposure. None of the systems had an overall performance equal or superior to that of a solvent-borne primer currently being used by state maintenance forces when applied to both abrasive-blasted and hand-cleaned surfaces. Pretreatments appeared to be effective in improving the performance of a coating having poor performance and did not significantly detract from the performance of a coating which already had good performance.

Pretreatments and Rust Converters

Rust converters were grossly detrimental to the performance of a primer when applied to 100% rusted steel which was wire brushed and exposed in the field; the type of surface they are generally designed to cover. Claims that rust converters actually transform rust to a different form could not be verified. No changes in the x-ray diffraction patterns of rust samples removed from panels and treated with rust converting systems could be detected. The three pretreatments evaluated in this study were effective in improving the performance of the primer with which they were overcoated on field exposed panels. Even the 100% rusted and wire brushed panels which were pretreated showed either some improvement in performance or at least no detriment to their performance. Only one pretreatment improved the performance of a primer under both accelerated test conditions and actual field exposure. However, that was the only pretreatment tested with the relatively poor performing primer applied over both accelerated test and field exposed panels. The panels treated with the remaining two pretreatments and exposed in the laboratory were overcoated with one of the best performing primers evaluated.

Surface-tolerant Latex Paints

Surface-tolerant latex paints were not tolerant of poor surface preparation. While some performed marginally well over clean steel, performance over rust was poor for all coatings of this type tested.

Nonhardening Waxy Paints

Nonhardening waxy type paints performed poorly in both accelerated and outdoor exposure testing on all surfaces.

Epoxy Mastics

Epoxy mastics generally performed well on the test panels. However, performance on a larger scale application did not match the performance anticipated from accelerated testing. Limitations on application due to pot life and temperature further restrict their utility. All but one of the epoxies tested restrict application to 50°F and above. The one which did not have a temperature restriction failed to achieve good intercoat adhesion. Scribe undercutting was moderate to severe for these samples, but blistering was only moderate. Panels appeared to undergo considerable underfilm deterioration without showing signs of distress on the surface.

Urethane Paints

The urethane coatings performed well under accelerated testing. However, their performance after 15 months exposure at the Golden Gate Bridge was not encouraging. None of the submittals met the requested VOC level and the poor performance for the set of panels exposed at the Golden Gate Bridge does not support a justification to evaluate coatings with a greater VOC content.

Solvent-borne Paints

The solvent-borne paint designated PB-193 and its modified versions, PB-197 and PB-202, appear to be the best coatings for application to hand-cleaned surfaces. They are essentially VOC-compliant at 260 grams per liter and gave performance equal to or better than the best of any other coatings evaluated over rusty steel in this project. Application of over 10,000 gallons by maintenance forces to hand-cleaned and abrasive-blasted steel has shown it to have none of the problems associated with multicomponent epoxy coatings which rated comparably under accelerated testing. Additionally, no other coating evaluated, when applied by brush, was as consistent in yielding film thicknesses equal to and above those specified.

RECOMMENDATIONS

Surface preparation by means of abrasive blasting should be employed whenever possible. When this is not feasible, two coats of primer conforming to PB-193, PB-197 or PB-202 appear to be equally effective when applied over a thoroughly hand-cleaned surface to a dry film thickness of 4 mils. Caltrans has used various finish coats over these primers with good success. These include various colors of an acrylic latex based coatings as well as an aluminum flake pigmented finish coat utilizing the same vehicle used in the primers, designated formulation PB-199.

The improvement in performance of the solvent-borne primer designated sample P-33, which was believed to have been brought about by the phosphoric acid based pretreatments warrants further investigation. If similar improvement can be obtained in the performance of other primers, use of these pretreatments would be recommended.

SAMPLE TESTING

CATEGORIZATION

A total of forty-one samples were submitted in response to announcements placed in both The Journal of Coatings Technology and American Paint and Coatings Journal. A listing of products submitted is shown in Appendix C. Samples were assigned code numbers which were used for identification throughout the study. Submitted samples were categorized by purported mode of action into the following groupings:

1. Pretreatments: These materials are designed to be applied to a rusty surface with which they react. They do not possess film-forming properties in themselves, but are designed to prepare the surface for subsequent coats of paint. Three such materials were submitted. These samples are designated P04, P25 and P27.

2. Rust converters: This is a broad classification which includes products which are claimed to react in some manner with the rust existing on a surface and convert it to either a different form of rust or to encapsulate it so as to render it inert. All of the samples submitted for this category claim to possess film formers, as well as the chemicals necessary to bring about the rust conversion. Six products were submitted in this category and an additional sample was placed in this category due to its purported mode of action. These samples are P03, P05, P06, P11, P14, P15 and P39.

3. Surface-tolerant latex paints: These materials do not react in an unusual manner with the rust, but are supposed to be less affected by surface contaminants than conventional

latex paints. Nine of the samples submitted can be placed in this category; P01, P02, P07, P16, P17, P18, P28, P40 and P41. Three additional samples, P08, P09 and P19 use a cementitious powder along with a latex to form a film.

4. Nonhardening waxy coatings: These are barrier- type films which do not dry to a hard condition. They are either wax or soap based coatings similar to greases which are claimed to encapsulate rust and prohibit formation of additional rust by the exclusion of oxygen and moisture. Three samples of this type were submitted; P10, P12 and P13.

5. Epoxy mastics: These high-build coatings utilize epoxy resins as the principal film forming material. They are multicomponent materials which are designed to be applied in relatively thick films to hand-cleaned surfaces. They protect the steel by encapsulation and usually contain flake type pigments such as aluminum to enhance their barrier properties. Six samples of this type were submitted; P24, P26, P34, P35, P36 and P37.

6. Urethane type: These were either single component moisture-cured or multicomponent urethane paints designed to encapsulate the rust similar to the epoxy mastic paints. Nine different urethane paints were submitted for application to hand-cleaned surfaces either as components of a system or as single coats designed to function as both primer and finish. These were not completely evaluated because they all exceeded the VOC limit of 250 grams per liter which was requested for submitted coatings. These samples were designated P20, P21, P22, P23, P29, P30, P31, P32 and P38.

7. Solvent-borne, air-drying paint: A VOC-compliant, phenolic resin-based paint, designated PB-193, being used by Caltrans as a steel primer was initially used as a control paint against which to compare the other coatings and as a

primer for converters or pretreatments which required additional paints. Its performance was so good that an additional solvent-borne paint was purchased to use in its place as a control coating. This new control coating, designated P33 was a red, rust inhibitive alkyd coating with a VOC content of 320 grams per liter. Modified formulations of PB-193, designated PB-197, PB-201 and PB-202, were additionally tested with results comparable to those obtained with PB-193.

SAMPLE PREPARATION

In April 1984, Translab was fortunate to acquire a box containing fifty-four rusted, previously painted 3in. x 6in. x 1in. hot rolled steel panels from the Golden Gate Bridge. These panels appear to be some type of shim plate which was used on the bridge. Because they had areas of intact and broken mill scale, rust and old paint, it was felt that they would make ideal substrates for application and testing of coatings and treatments for exterior evaluations and were retained for that purpose. This provided one set of substrates for testing purposes.

While clean steel panels are readily obtainable for laboratory evaluations, it was necessary to establish a source of rusted panels for additional laboratory and field evaluations. After some trial and error, the following procedure was established to prepare rusted panels for testing purposes:

1. Abrasive blast 6in. x 12in. ASTM D609 type 1 steel panels to a near-white finish with a 1 to 2 mil surface profile.

2. Expose panels for 24 hours in an ASTM B117 salt spray cabinet.

3. Rinse panels thoroughly with deionized water.

4. Expose panels for an additional 6 days in an ASTM D2247 type A1 humidity cabinet.

5. Remove panels and store for a minimum 24 hours before using.

This procedure was used throughout the project and produced very uniformly rusted panels with a moderate degree of salt contamination. Rust removed from panels prepared in this manner contained an average of 225 ppm chloride ion.

Even though the coatings being evaluated in this project were intended for application to rusty surfaces, it was felt that they should also be expected to perform well on clean surfaces. Consequently, the coatings were also evaluated on 100% near-white abrasive-blasted panels. Laboratory accelerated testing consisting of ASTM B117 salt spray exposure and ASTM D2247 type A1 humidity exposure was performed on each coating or pretreatment applied to three types of laboratory panels; ABO or abrasive blasted only indicates panels which were blasted to near-white metal and coated; WBO indicates panels which were wire brushed to remove all loose rust immediately prior to application of the material; WBR indicates WBO panels which additionally received a thorough rinsing with deionized water and were allowed to dry immediately prior to treatment. Generally, each material was evaluated on a minimum of six laboratory panels. The lower half of each 6in. x 12in. panel was given an X-shaped scribe through the coating to the base metal prior to exposure.

Following laboratory evaluations early in the project, and concurrently as the project progressed, materials were also evaluated on panels exposed on the Golden Gate Bridge. Materials were brush applied to the heavy, 1"x3"x6" panels designated GGB as well as to ABO and WBR panels as mentioned above. It was decided that where laboratory data indicated very poor performance for a material, it would not be beneficial to continue testing the material on exterior exposure. As a result, preparation of panels for exposure on the Golden Gate Bridge for ten of the samples was discontinued. These were sample numbers P01, P07, P08, P09, P10, P12, P13, P19, P20 and P28. These samples had ASTM D610 rust ratings of 6R after only 300 hours of salt spray exposure. A rating of 5R for bridge exposed panels was considered failure.

All samples were brush applied to the test panels throughout the project. This was contrary to the literature accompanying several of the samples but was done intentionally. This is because it is highly probable that the same conditions which prohibit the use of abrasive blasting for surface preparation may also prohibit the use of power spray equipment either due to lack of sufficient area requiring coating or lack of access. Crew size may be restricted for various reasons or traffic conditions may be restrictive. Any of these reasons could prohibit the use of spray equipment, but it is difficult to imagine a situation where brushing would be restricted.

The pretreatment and rust converter type coatings were generally not intended to comprise complete coating systems in themselves, although some of the rust converters indicated they could perform satisfactorily under mild exposure conditions. Laboratory test panels were initially prepared using the sample as instructed and then priming with Caltrans primer PB-193 because several of the converters indicated they should be overcoated with an oil-type primer. PB-193 was also applied to control test panels as if it were a sample. It soon became apparent that PB-193 was performing so well that when applied as an overcoat it was difficult to tell differences in performance brought about by the rust converter or pretreatment. Consequently, sample P33 was purchased to replace PB-193. All of the accelerated laboratory test panels were tested using PB-193 as an overcoat except for pretreatment P27 which was overcoated with P33. Panels prepared for exposure on the Golden Gate Bridge, however, were all overcoated with P33. Additionally, one half of each pretreatment or rust converter panel prepared for Golden Gate Bridge exposure was given two latex finish coats. The finish coats mitigated weathering effects to such an extent that little differentiation in performance of topcoated areas was distinguishable after two years of exterior exposure. Consequently, results tabulated in this report are confined to untopcoated areas.

DISCUSSION

1. Pretreatments: The three pretreatments submitted appear to be very similar in composition being basically phosphoric acid solutions of differing strength with varying amounts of proprietary surfactants and wetting agents. They are water thin and readily applied by brush. They caused rusty areas to appear on the surface of the ABO panels and left large areas of white deposits after drying. The instructions for sample P04 said to rinse the surface with tap water after allowing the solution to react and then apply a conventional primer. Samples P25 and P27 did not require rinsing after treatment.

2. Rust converters: These materials were brush applied to the various panels as instructed. Samples P03, P05, P11, P14 and P15 all had the same basic appearance and handling properties; white, relatively thin liquids which were easily applied by brush. Instructions said to apply them to rusty surfaces and allow time for drying prior to application of an oil-base topcoat. Almost immediately following application, the white color of the coatings began to darken and became a glossy black color, generally within a half hour of application. Sample P06 was also white in color, but had a strong alcohol-like odor associated with it. Its instructions said to rinse the surface with tap water about eighteen hours following application to remove unreacted material and then apply an oil-base primer and finish coat. It slowly turned black over a two hour period. Its VOC content was determined to be 739

grams per liter even though it contained 51% water. All samples had been prepared prior to determination of the VOC content, so testing was continued. Sample P39 was brown initially and turned a glossy black following application similar to the other rust converters. Its instructions indicated that no additional coats were necessary following the initial application and it was evaluated accordingly. Only two of the samples, P05 and P14, claimed to actually change the rust to a different chemical form, magnetite. The others claim to convert the rust into a black, corrosion-resistant coating without making any claims that a chemical change has taken place. The literature accompanying the samples implies that this conversion may be an encapsulation process. Attempts that were made to verify the claims for chemical conversion are detailed in the results section of this report.

3. Surface-tolerant latex paints: This was the largest category of samples submitted, probably because of the requirement that the coatings and pretreatments meet the 250 gram limit on VOC content. Except for the three cementitious paints, P08, P09 and P19, which were two-component materials, these resembled latex house paints in application and handling characteristics. Samples P01 and P28 were modifications of the same primer formulation. Samples P16 and P17 were finish coats intended to be applied over primers P02 and P18. An additional finish coat was submitted for those same two primers, but was not assigned a project sample number. Samples P40 and P41 were acrylic latex primers similar to primers currently specified by Caltrans. The cementitious primers were difficult to apply following mixing due to their high viscosity. They dried rapidly, but had poor leveling and, as a result, their initial appearance was the worst of any samples tested. Sample P07 should perhaps have been placed in a category by itself. It is a water-borne mixture of film formers and volatile corrosion inhibitors. Application properties were comparable to the other latex

coatings tested.

4. Nonhardening waxy coatings: As implied by the name for this category, these materials resembled greases more than conventional coatings. Uniform brush application was difficult and handling of test panels required considerable care. Sample P10 was pigmented with aluminum. Pigmentation for samples P12 and P13 was not determined.

5. Epoxy mastics: These were multicomponent materials requiring thorough mixing of each component prior to blending the two components together at the specified mix ratios. Some of these recommended thinning the first coat when applying the coating to hand-cleaned steel. Mix ratios varied from 6:1 to 1:1. Brush application of these coatings produced nonuniform films with poor appearance. Leveling characteristics were poor. Sample P36 was supplied as a low viscosity epoxy primer to go beneath sample P35 to better wet the hand-cleaned surface. Sample P35 was evaluated both with and without sample P36.

6. Urethane coatings: As mentioned above, none of the moisture-cured or multicomponent urethane paints submitted met the requested VOC limit of 250 grams per liter. Nevertheless, it was considered to be of interest to include some coatings of this type in the study because it is a possibility that industry could be granted exemptions from meeting VOC levels. Three systems were evaluated. Samples P22 and P23 were applied as finish coats over the two coat primer system designated P21. Application properties were good. Sample P38 was evaluated in accelerated laboratory tests only.

7. Solvent-borne, air-drying paints: These were considered the standard paints against which to compare application and performance properties of submitted samples. Paint PB-197 is an updated version of PB-193 with a minor change in solvent

content. These have been used with increasing frequency by maintenance crews on the San Francisco-Oakland Bay Bridge since early 1985 with good results. The most recent revision of the formulation is PB-201. These primers contain 250 to 260 grams VOC per liter and do not require thinning to achieve satisfactory brush application. Sample P33, containing 350 grams VOC also had satisfactory application properties.

EXPOSURE RESULTS

Accelerated laboratory testing of materials submitted and prepared as outlined above was conducted according to ASTM B117, Salt Spray (Fog) Testing, and ASTM D2247, Testing Coated Metal Specimens at 100% Relative Humidity. Panels were rated and photographed a minimum of three times during 1000 hours of exposure. Ratings were made visually according to ASTM D610 for degree of rusting and according to ASTM D714 for size and frequency of blistering.

Concurrently with accelerated laboratory testing, panels were prepared for exposure on a test rack located beneath the Golden Gate Bridge. In the following discussions, these panels are referred to as bridge panels. Panels were not prepared for Golden Gate Bridge exposure if the test panels were rated as having greater than 1% rust (ASTM D610 rating less than 6R) after 300 hours in the salt spray cabinet. This applied to all samples except those for which panels were prepared prior to salt spray results. In these cases, all panels which had been prepared for exterior exposure were used, but no additional panels were prepared. Panels were given rust and blister ratings according to ASTM D610 and D714 at intervals of approximately three months. Panels were additionally rated for creepage from the scribe line (ASTM D1654-Procedure A) at the conclusion of the exposure period. Ratings are summarized graphically for each sample. Because ASTM D714 blister ratings contain two components, frequency and degree, a modified procedure was used to present that data graphically to simplify comparison. The numerical rating for degree of blistering was multiplied by a number established for frequency according to the scheme shown in Table I.

FREQUENCY	NUMERICAL RATING
None	10
Very Few	9
Few	8
Few-Medium	7
Medium	6
Med. Dense	5
Dense	3
Very Dense	1

Numerical Ratings for Blister Frequency

TABLE I

Thus, a panel with a blister rating of 8 Few would yield a combined blister rating of 64. This serves as a useful means of comparing trends over the course of exposure of a sample, but should not be considered by itself to be an indicator of good or poor performance. Blistering was often associated with scribe undercutting, but some of the samples showed little or no tendency to blister while experiencing severe undercutting at the scribe. Scribe ratings for panels exposed at the Golden Gate Bridge site are presented for each category in the following discussion.

Pretreatments

[Figures I, II and III]

Despite manufacturer's claims to the contrary, pretreatments applied over clean steel generally yielded performances superior to those of pretreatments applied over rust. Performance of two of the pretreatments over previously painted panels was slightly better than performance over abrasive blasted steel, however, reduced performance over a 100% rusted surface indicates the improved performance was probably due to the presence of the previous paint system. One of the pretreatments, when overcoated with a good performing primer (PB-193), was detrimental to primer performance under accelerated testing while one showed very slight improvement. Salt spray panels treated with sample P04 performed marginally better than similar panels painted with only PB-193. Bridge panels did not reflect this improved performance. Sample P25 was detrimental to the rust resistance of PB-193 in both accelerated testing and field exposure; blister resistance was generally improved. Sample P-27 greatly improved the rust rating of P-33 under accelerated testing but rusting on the previously painted bridge panels increased. Blistering was much more severe in the salt spray chamber and slightly worse on bridge panels except for the abrasive-blasted panel where blister frequency improved from medium to few. ASTM D1654 ratings for the various panels are shown in Table II. Blister and rust ratings for accelerated testing and Golden Gate Bridge exposed panels treated with pretreatments are shown in Figures I, II, and III.

Sample	Panel Type		
	GGB	ABO	WBR
P04	4	3	3
P25	2	3	2
P27	0	4	2
P33	3	3	1
PB-193	6	4	4

ASTM D1654 Scribe Ratings for Pretreated Panels

TABLE II

Rust Converters

[Figures IV through X]

Salt spray performance of panels treated with rust converter type paints was good for all samples which were overcoated with PB-193. Sample P39, which did not receive additional coatings but was evaluated alone, failed within the first 200 hours of exposure (rust rating 4R; 10% rust). Rust converter panels exposed on the Golden Gate Bridge showed a remarkable resemblance to each other. Graphs depicting their exposure history, shown in Figures IV through X, can almost be superimposed on each other. Rust ratings for P33 on the GGB panel went from 9 representing 0.03% rust at 16 months of exposure to 7 representing 0.3% rust at 25 months exposure. Ratings for the rust converter treated GGB panels clustered around 8 representing 0.1% rust after 25 months. The ABO control panel painted with P33 only was rated 5 for 1% rust at the end of 25 months. Comparable rust converter treated panels rated 7 to 8 representing 0.1% to 0.3% rust. Sample P39 alone rated 4 (10% rust) after the same time interval. Apparently the rust converters were able to provide additional protection to both the clean, uncontaminated steel and the steel with minor rust and mill scale. Performance of rust converters applied to rusted, wire brushed and rinsed panels with mild salt contamination was very poor. All of these, except the panel coated with P06 which was rated 3 for 16% rust, were removed from exposure on the bridge following the 25 month rating due to complete perforation of the steel. The control panel was rated 4 (10% rust) at that time. The benefit of topcoating was readily apparent on these panels. Whereas the rust converter treated and primed portions of the panels were perforated with apparently no base metal remaining, topcoated areas, although blistered, retained considerable strength and had intact surfaces. Primer film over the rust converters was cracked and broken. Scribe ratings for the panels are shown in Table III. GGB panels for samples P11 and P15 were missing from the exposure rack on the date of the last evaluation and scribe ratings were consequently unavailable.

Sample	Panel Type		
	GGB	ABO	WBR
P03	0	4	0
P05	1	4	0
P06	2	4	2
P11	NR	6	0
P14	3	3	0
P15	NR	3	0
P39	3	0	0
P33	3	3	1
PB-193	6	4	4

ASTM D1654 Scribe Ratings for Rust Converter Treated Panels

TABLE III

Surface-Tolerant Latex Paints

[Figures XI through XX]

Of the twelve samples received in this category, only six were ultimately applied to panels for exposure at the Golden Gate Bridge. Samples P01, P07, P08, P09 and P19 were discarded as candidates due to excessive rusting when applied to the ABO test panels and subjected to accelerated testing in the salt spray cabinet. Sample P28, which was a variation of sample P01, solidified in the container prior to being evaluated. An ABO panel for sample P07 had been prepared prior to salt spray results. It was placed on the exposure rack at the bridge and began to fail within one day. Similarly a GGB panel for sample

P19 had been prepared prior to salt spray results. Exposure on the bridge test rack confirmed the futility of further evaluation. Samples P02 and P18 were different primer formulations submitted by the same company. They were intended to be finish coated with with samples P16, P17 or another sample not assigned a project number, but designated 960 finish. Several of these combinations were applied to panels with similar results; paints applied to clean steel performed well while application of the same systems to even mildly contaminated rusty steel resulted in poor performance. Samples P40 and P41 performed the best of all samples in this category in terms of rust and blister resistance. Their performance was marginally better than that of sample P33, but not as good as that of state specification paint PB-193. Scribe ratings for bridge panels are shown in Table IV. Exposure results are shown in Figures XI through XX.

Sample	Panel Type		
	GGB	ABO	WBR
P02/P16	3	4	0
P07	–	0	–
P18/P16	0	7	5
P18/P17	6	6	0
P18/960	0	3	0
P19	4	–	–
P40	2	3	0
P41	1	3	0
P33	3	3	1
PB-193	6	4	4

ASTM D1654 Scribe Ratings for Surface-Tolerant Latex Paints

TABLE IV

Nonhardening Waxy Paints

[Figures XXI, XXII and XXIII]

The three samples submitted in this category were not applied to panels for exposure on the Golden Gate Bridge due to their poor performance in accelerated testing. Panels exposed in the salt spray cabinet were rated at greater than 50% rust prior to completion of 1000 hours of exposure. This type of coating would not normally be expected to be capable of supporting blisters. Blister ratings were assigned due to the appearance of blister-like areas on the surface of two of the panels which were found to be semisolid eruptions of rust from the panel surface. Exposure results are shown in Figures XXI, XXII and XXIII.

Epoxy Mastics

[Figures XXIV through XXXI]

Exposure results for the six samples submitted in this category are shown in Figures XXIV through XXXI. Salt spray performance of these coatings was overall the best for any of the categories evaluated. All of the materials in this category were ultimately evaluated on panels at the Golden Gate Bridge. The following is a brief synopsis for each of these materials.

Sample P24 had a specified mix ratio of 6:1 and a minimum application temperature rating of 50°F. The sample was white pigmented. It claimed excellent one coat performance when applied to hand-cleaned steel to a minimum thickness of 3 mils. Film thickness after one coat was 1.5 to 2 mils. Another coat was applied after 24 hours to yield 5.5 to 6.5 mils total film thickness. The paint mixed easily and had good brush application properties. Rust ratings after 1000 hours salt spray exposure were almost identical to the ratings of the panels exposed on the Golden Gate Bridge after 25 months with the poorest rating a 7 on the GGB panel representing 0.3% rust.

Blistering on the bridge panels was noted within three months of placement for the WBR panel and after one year for the GGB panel. Chalking was severe even though the panels received little direct sunlight. No blistering occurred under accelerated testing. The best performing panel had greater than 0.25 inch of undercutting on either side of the scribe.

Sample P26 had a mixing ratio of 1:1 with a 50°F limit on application temperature. It was aluminum pigmented and claimed good one coat performance when applied to a minimum of 5 mils. The first application yielded a dry film thickness of 5 to 6 mils, but following the manufacturers recommendations, another panel was prepared using two coats applied 24 hours apart. Dry film thickness for the two coat panel was 7 to 12 mils. Accelerated testing was performed on one coat panels only. Rust ratings following salt spray exposure were comparable to ratings for the one coat bridge panels, with a rating of 5 for the WBR panel in the salt spray and a rating of 4 for the WBR bridge panel following 25 months exposure. These ratings are equivalent to 3 to 10% rust. No blistering was found in the accelerated test panels but moderate blistering occurred on the bridge panels. Bridge panels coated with two applications performed superiorly to the one coat panel with only very minor rusting found after 25 months and only one blister on the GGB panel which disappeared. Chalking or crazing of the surface was severe at the bridge site.

Sample P34 had a 1:1 mixing ratio and was pigmented with aluminum. No minimum application temperature was stated. It was applied in one coat for accelerated testing and panels with both one and two coats were prepared for bridge site evaluation. Rust resistance was good under accelerated testing with no more than 0.1% rusting after 1000 hours. Rust ratings of 4 to 6 were found on the bridge panels with one coat of paint and ratings were 6 to 7 on the bridge panels with two coats of paint after 25 months of exposure. The second coat became completely delaminated from the first coat during the 25 months of exposure. Blistering was moderate on the bridge panels and not as severe as on the accelerated test panels. Chalking was severe.

Sample P35 had a 4:1 mix ratio and was also aluminum pigmented. It claimed to be capable of application at temperatures down to 25°F. It was evaluated in the laboratory as a one coat system and as a second coat over sample P36. Maximum rusting in the salt spray cabinet was rated 8 representing 0.1% rust. Blistering was moderate. Bridge site exposure was performed with the paint applied in one coat unthinned as was done for accelerated testing, with two coats unthinned, and with two coats where the first coat was thinned 20%. As can be seen on the graphs in the appendix, there were minor differences in rust and blistering performance between the panels with one coat and those which received two coats. Blistering and rusting actually became slightly worse when thinner was added to the first coat of paint on the two coat panels. Scribe undercutting also became worse. Two unthinned coats were markedly superior to one unthinned coat. Chalking was severe and notably detracted from the appearance of the bridge panels.

Sample P36 was promoted as a rust penetrating sealer designed to have very low viscosity to enable it to penetrate, encapsulate and tightly bind any rust to the steel surface. No application temperature restrictions were indicated and the material was unpigmented. It was intended to function as a first prime coat with sample P35 applied as the next prime coat. The mix ratio for the sample was 3:1. Although the instructions indicated the coating could be brush applied, they also said to not apply the material in heavy coats. Laboratory application by brush could not be done without generating runs and sags which were uniformly distributed over the panels. Accelerated testing showed comparable blistering when compared with one coat of P35 without P36 and a slight increase in rusting with the use of P36. Bridge site exposure showed comparable blistering with its use compared to P35 evaluated as one coat alone and a definite improvement in rust resistance. The WBR bridge panel with one coat of P35 had a rust rating of 2 representing 33% rust after 25 months exposure while the panel pretreated with P36 had a rust rating of 7 representing only 0.3% rust. Two coats of P35 gave comparable rust ratings to the P36/P35 combination. The dry film thickness of the combination ranged from 5 to 8 mils and two coats of P35 had a dry film thickness of 10 to 15 mils.

Sample P37 was an aluminum pigmented epoxy mastic with a 1:1 mix ratio. It claimed to give excellent performance when applied in one coat. Accelerated testing of one coat resulted in poor rust resistance with the best performing panel rated 4 representing 10% rust after 1000 hours. Bridge panels showed comparable results after 25 months; however, the WBR bridge panel performed better (rust rating 5 or 3%) than the ABO bridge panel (rust rating 3 or 16%). Two coats performed considerably better on bridge exposure with the poorest panel rated 8 for 0.1% rust after 25 months. Thinning of the first coat did not improve performance. As with the other epoxy mastics evaluated, chalking was severe, and additionally this sample developed a brownish discoloration on exposure. Scribe ratings for the epoxy mastic panels exposed on the Golden Gate Bridge are shown in Table V.

Sample	Panel Type		
	GGB	ABO	WBR
P24	1	4	2
P26-1ct.	0	6	3
P26-2cts	0	7	7
P34-1ct.	3	3	2
P34-2cts	4	NR	3
P35-1ct.	NR	7	2
P35-2cts	2	7	2
P35-2cts 1st thinned	0	4	2
P36/35	0	5	2
P37-1ct.	NR	6	4
P37-2cts	4	7	4
P37-2cts 1st thinned	2	4	3
P33	3	3	1
PB-193	6	4	4

ASTM D1654 Scribe Ratings for Epoxy Mastic Paints

TABLE V

Urethane Coatings

[Figures XXXII and XXXIII]

Due to their high VOC content, these samples were not considered to be within the scope of this project. Nevertheless, some panels were prepared and evaluated. Accelerated testing of two systems designated P22 over P21 and P23 over P21 showed excellent rusting resistance and moderate blistering resistance as shown in Figure XXXII. P21 was a two prime coat system of moisture-cured urethanes using an aromatic polyisocyanate and pigmented with aluminum. VOC levels were approximately 450 grams per liter. Sample P22 was an aluminum pigmented moisture-cured urethane also utilizing an aromatic polyisocyanate. Sample P23 was an orange colored two-component polyester/urethane utilizing an aliphatic polyisocyanate. Late in the project, a decision was made to proceed with exposure of panels coated with these two systems on the test rack at the Golden Gate Bridge. After 15 months of exposure the panels have the rust, blister and scribe ratings shown in Table VI.

Sample	Panel Type		
	GGB	ABD	WBR
P22/21 rust/blister	7R,6 Few	8R,5 Few	8R,4 Few
P23/21 rust/blister	8R, 10	9R, 10	8R,3 Few
P22/21 scribe	3	4	3
P23/21 scribe	3	6	2

Rust, Blister and Scribe Ratings for Urethane Coated Panels
(ASTM D610, ASTM D714 and ASTM D1654 respectively)

TABLE VI

Sample P38 was a moisture-cured epoxy urethane mastic designed to cure at temperatures as low as 0°F. Its relatively poor performance as shown in Figure XXXIII can partially be attributed to its having been brush applied which yielded a striated surface with a dry film thickness of 3 to 5 mils.

Solvent-Borne, Air-drying Paints

[Figures XXXIV, XXXV and XXXVI]

These coatings, as previously mentioned, were used as control coatings against which to compare the performance of the submitted samples. Samples PB-193, PB-197 and PB-202 are slight variations in the same formulation and are currently being used by Caltrans maintenance crews throughout the state. Brush application properties are good and, contrary to experience with almost all other coatings, painters have had to be cautioned repeatedly to avoid applying the paint too thickly. Volume solids are almost 70%. Rust resistance in accelerated testing and bridge exposure testing has been excellent as shown in Figures XXXIV and XXXV. Combined blister ratings of less than 50 are almost 100% due to blisters associated with the scribed areas of the panels. Sample P33 was purchased from a local paint store in an effort to find a generic type paint similar to PB-193 with less effective corrosion resistance. Test results (Figure XXXVI) show this goal was achieved. Sample P33 nevertheless showed relatively good performance when used alone. These coatings function by their ability to wet the surface of the rust particles by polar attraction and encapsulate it within their matrix (5). Application properties were excellent. The P33 GGB panel had a rust rating of 7 after 25 months on the Golden Gate Bridge site compared to a rating of 8 for the PB-193 GGB panel. The WBR panel with more visible contaminants, rated 4 for sample P33 whereas the PB-193 WBR panel maintained a rating of 8.

RUST CONVERSION

Figures XXXVII, XXXVIII and XXXIX

All of the primers currently used by Caltrans, except for the zinc-rich type, utilize iron oxide as a pigment ingredient. Red iron oxide primers are often called for in architectural specifications for use on interior metals. Test sample P33 is a red iron oxide primer. The iron oxides are either synthetically manufactured materials or derived from natural ores. They are generally classified as inert pigments. Manufacturers of five of the rust converting paints claim that their product converts rust on a steel surface to an inert component in a plastic film. Two of the products, P05 and P14, claim to actually bring about an electrochemical transformation of the rust which converts it to an inert material similar to a pigment. Evidence that this transformation is occurring is supposed to be the color change which each of the converters evaluated underwent. Each was applied as a milky colored liquid which changed to a black layer on the steel as drying took place.

Several attempts were made to verify these claims. Initally, samples of rust for x-ray diffraction were prepared using rust removed from the panels by wire brushing. The rust was powdered, mixed with 2% x-ray briquetting powder, and pressed in a hydraulic press to form pellets. The pellets were then examined through x-ray diffraction to characterize the untreated rust. Its predominant component is Fe_2O_3. Two coats of the pretreatments were then applied to the pellets. Subsequent examination of one of the pellets treated with a tannic acid based pretreatment revealed significant changes in the diffraction pattern. Close examination of the resulting pattern, however, yielded a match with barium sulfate, a filler which was found to be a component of the pretreatment.

Portions of powdered rust were then weighed into ceramic crucibles. Each of the seven rust converters was then added to the rust, thoroughly mixed and allowed to dry under laboratory conditions of 77°F and 50% relative humidity for one week. The resulting pellets were then removed from the crucibles and each was ground to a fine powder in a freezer mill under liquid nitrogen. The resulting powders were prepared for x-ray diffraction analysis using a back-packing technique with no additives. There were no detectable changes in the diffraction patterns for any of the samples compared with untreated rust.

No crystalline changes occurred. Diffraction patterns of the untreated and treated rust are shown in Figures XXXVII, XXXVIII and XXXIX. Patterns are only shown for rust treated with the two converters which claimed to react with the rust. Patterns for the remaining converters were the same. Rust conversion for all seven rust converter samples is apparently an incorporation of the rust into the paint film. The color change wherein the white converter becomes a black film does not depend on the presence of rust. Converters applied to freshly abrasive-blasted steel panels experienced a color change identical with that seen on the rusty panels.

TOXICITY TESTING

Toxicity evaluations were only performed on PB-197 because it is the only coating among those evaluated in this study for which further use is anticipated by Caltrans. Data are only for fresh paint, as opposed to weathered paint, which would be the most likely type of paint to be discharged into bodies of water in significant quantities. Tables VII, VIII and IX show bioassay data for Physa, a genus of air-breathing, fresh-water snails. Films of dried paint were ground to a fine powder in a freezer-mill and added to water containing Physa eggs at varying concentrations. The EC_{50}, effective concentration which inhibited hatching of 50% of the eggs, was determined to be 46.1 mg of dry paint per liter of solution. Tables X, XI and XII show bioassay data for Daphnia, a genus of small freshwater crustaceans. The EC_{50}, concentration which rendered 50% of the Daphnia nonmotile after 96 hours, was determined to be less than 7.5 mg dry paint/l. An additional evaluation intended to determine the no- effect concentration on a species of algae, Selenastrum Capricornutum, was made. Those results are shown in Table XIII. The lowest concentration of dry paint evaluated, 50 mg/l, resulted in a 24.2% reduction in the algae population. The no- effect concentration was consequently not found through this evaluation.

TABLE VII

PB-197 Physa Bioassay

concentration mg/l	number of eggs tested	number of eggs not hatched	% of eggs not hatched
10,000	42	42	100
5,000	34	34	100
2,500	29	29	100
0 control	25	1	4

EC_{50} not calculated

TABLE VIII

PB-197 Physa Bioassay

concentration mg/l	number of eggs tested	number of eggs not hatched	% of eggs not hatched
2,540	33	33	100
1,260	41	41	100
625	36	35	97
312	31	29	94
158	30	19	63
0 control	46	2	4

EC_{50} not calculated

TABLE IX

PB-197 Physa Bioassay

concentration mg/l	number of eggs tested	number of eggs not hatched	% of eggs not hatched
200	43	43	100
100	28	28	100
50	29	16	55
25	44	6	14
0 control	46	2	4

EC_{50} (mg/l) = 46.1

TABLE X

PB-197 Acute Daphnia Ranging Bioassay

concentration mg/l	nonmotile after 48 hrs	96 hrs
1,000	5	5
500	5	5
250	5	5
125	0	5
0 control	0	0

1 replicate each with 10 Daphnia neonates in each replicate

TABLE XI

PB-197 Acute Daphnia Bioassay

concentration mg/l	replicates number nonmotile after 96 hrs		
	A	B	C
125	10	10	10
62.5	10	10	10
31.25	10	1	10
15.8	10	2	10
7.5	10	10	10
0 control	1	1	1

EC_{50} (mg/l) < 7.5

TABLE XII

PB-197 Acute Daphnia Bioassay

concentration mg/l	replicates number nonmotile after 96 hrs		
	A	B	C
50	10	10	10
25	10	10	10
13	0	10	10
6	0	0	4
3	0	0	0
0 control	0	0	0

EC_{50} (mg/l) < 7.5

TABLE XIII

PB-197 Selenastrum Capricornutum Bioassay

concentration mg/l	algae population cells/ml	% reduction
0 control	3.839314E5	–
50	2.910745E5	24.2
100	1.290499E5	66.4
200	6.43208E4	83.3
400	3.7739E4	90.2

FIELD EVALUATIONS AND IMPLEMENTATION

In the summer of 1983, three epoxy mastic type coatings were applied to hand-cleaned steel beams located on the ground in the maintenance yard at the San Francisco-Oakland Bay Bridge. Plans were to apply epoxies which performed satisfactorily under this test to areas of bridges on the northern California coast which have historically been difficult to maintain. Following success in these areas, application to an entire bridge was anticipated. Moderate rusting was noted after less than 9 months exposure for all three systems. Due to their poor performance, plans for further application of these materials were abandoned. Additionally, discussions with maintenance painters revealed a number of problems inherent with these systems. Restricted or difficult access to the areas on bridges which are most in need of painting means only small quantities of a material are needed per use. Limited pot life means that only small quantities can be mixed at a time, yet mix ratios other than 1:1 are difficult to portion when less than complete packages are required.

One of the first large field applications of coatings intended for application to hand-cleaned steel by Caltrans occurred in the fall of 1984 at the Noyo Harbor Bridge in Fort Bragg. Two rust converter type coatings along with state specification paint PB-193 were applied to hand-cleaned surfaces. The paints were finish coated with state specification latex finish coats. Areas coated with the rust converter paints required repainting after one year of exposure. Rust ratings for these areas were as low as 4 to 5 per ASTM D610 while areas primed with PB-193 were rated 9 to 10.

An order for 2,000 gallons of PB-193 was delivered to maintenance forces in the San Francisco Bay Area in mid 1985. It was distributed to painting crews on toll bridges in the Bay Area for use on hard-to-clean areas. Due to its good performance, over 10,000 gallons of it or its successor formulations have been ordered since 1985. PB-201 and PB-202, successors to PB-193, have recently been specified for use in several bridge painting contracts over blast-cleaned surfaces and for spot painting of hand-cleaned rusted areas on a number of sign bridge structures.

LITERATURE REFERENCES

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2. California Code of Regulations, Title 26, Section 22-66699.

3. Moore,N.L., Private Conversation, Caltrans Office of Structures Maintenance and Investigations, April 1988.

4. Warness, R., "Low Solvent Primer and Finish Coats for Use on Steel Structures," California Department of Transportation, Report No. FHWA/CA/TL-85/02, January 1985.

5. Deanin, R.D., Frondistou-Yannas, S., "Coatings for Non-Blast Cleaned Highway Metals," Report No. FHWA/RD-82/125, September 1982.

APPENDIX A

FIGURES

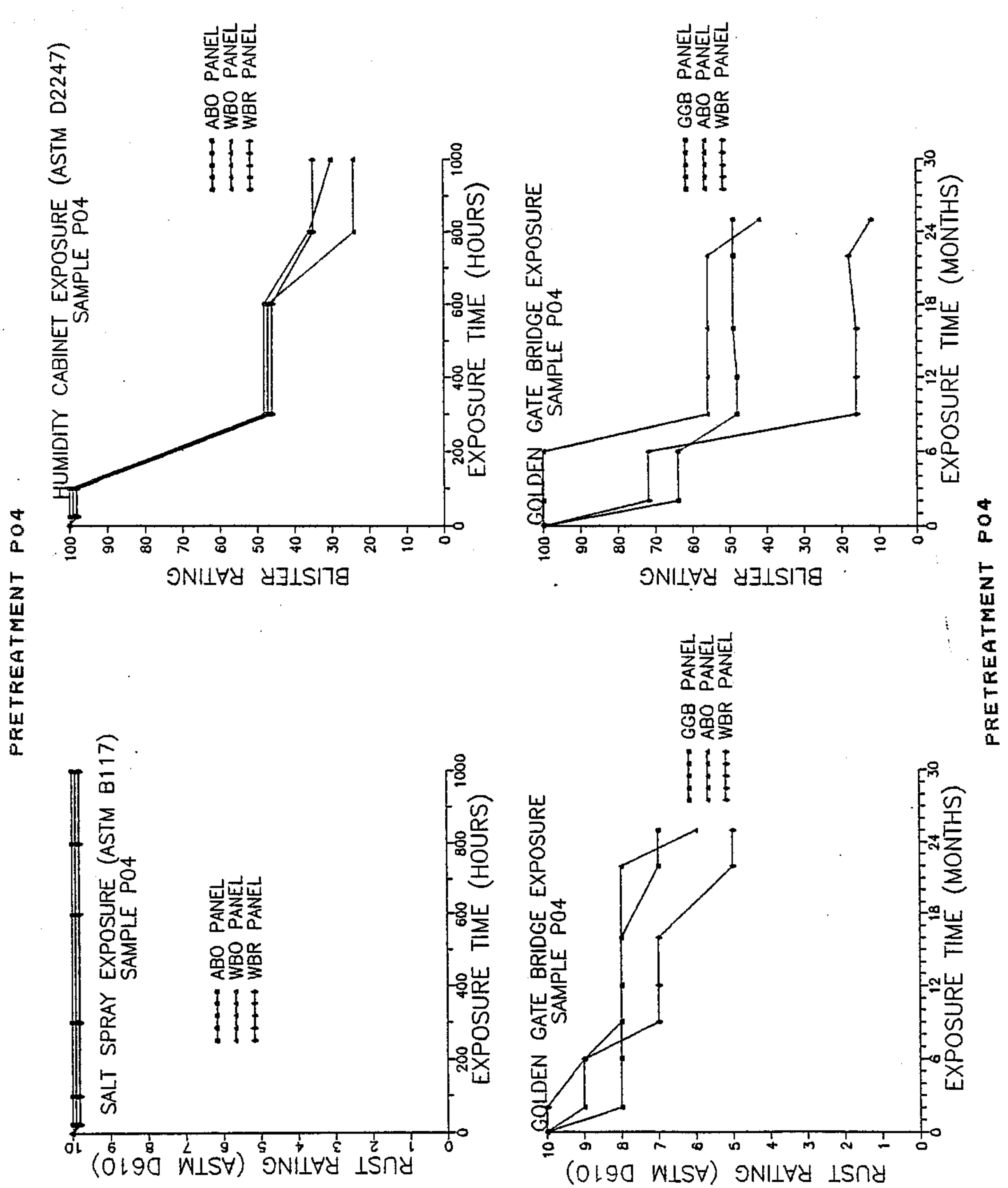
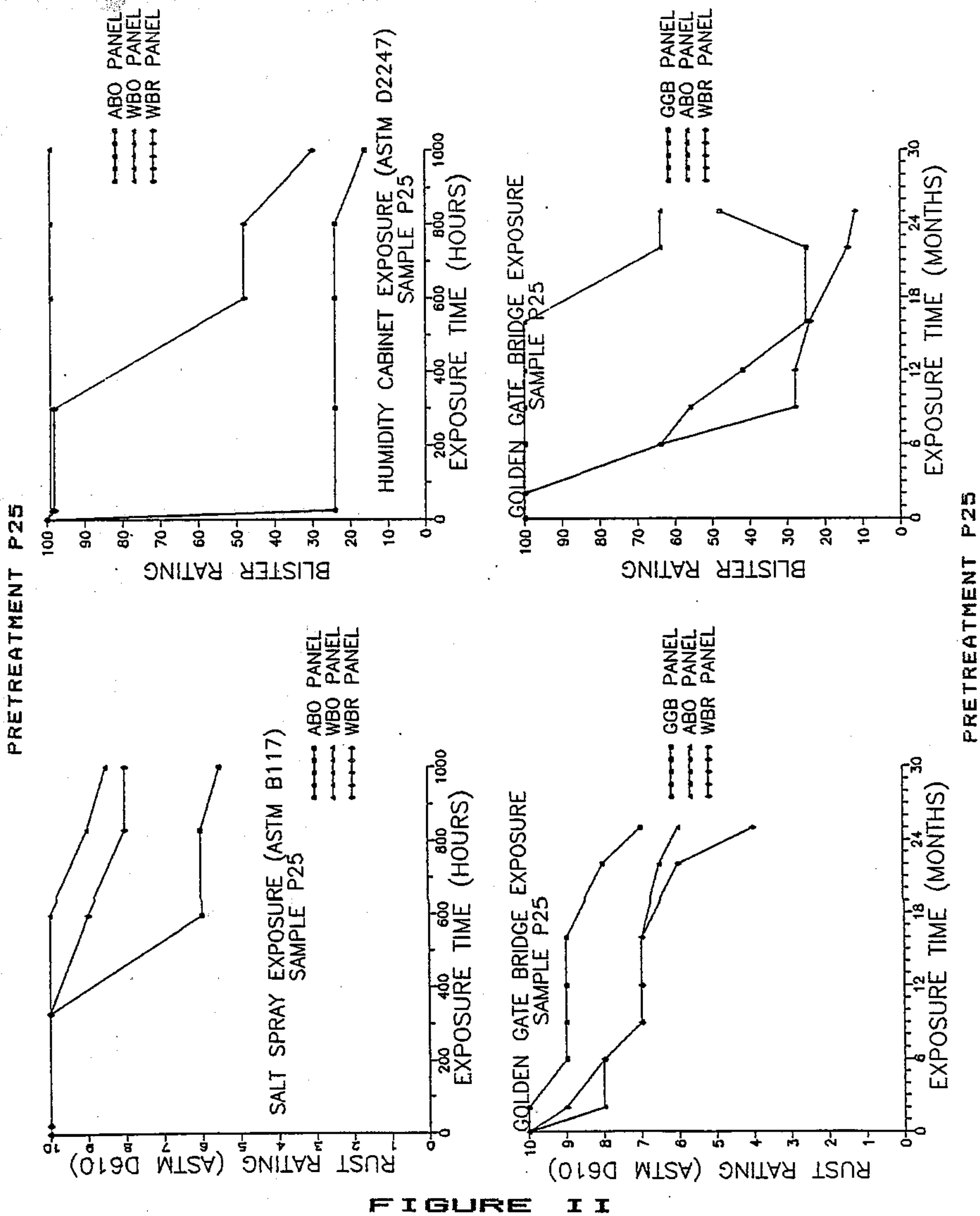

PRETREATMENT P04
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P04
ABO PANEL
WBO PANEL
WBR PANEL
BLISTER RATING
EXPOSURE TIME (HOURS)
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P04
ABO PANEL
WBO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
PRETREATMENT P04
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P04
GGB PANEL
ABO PANEL
WBR PANEL
BLISTER RATING
EXPOSURE TIME (MONTHS)
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P04
GGB PANEL
ABO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)

FIGURE I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SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P25
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
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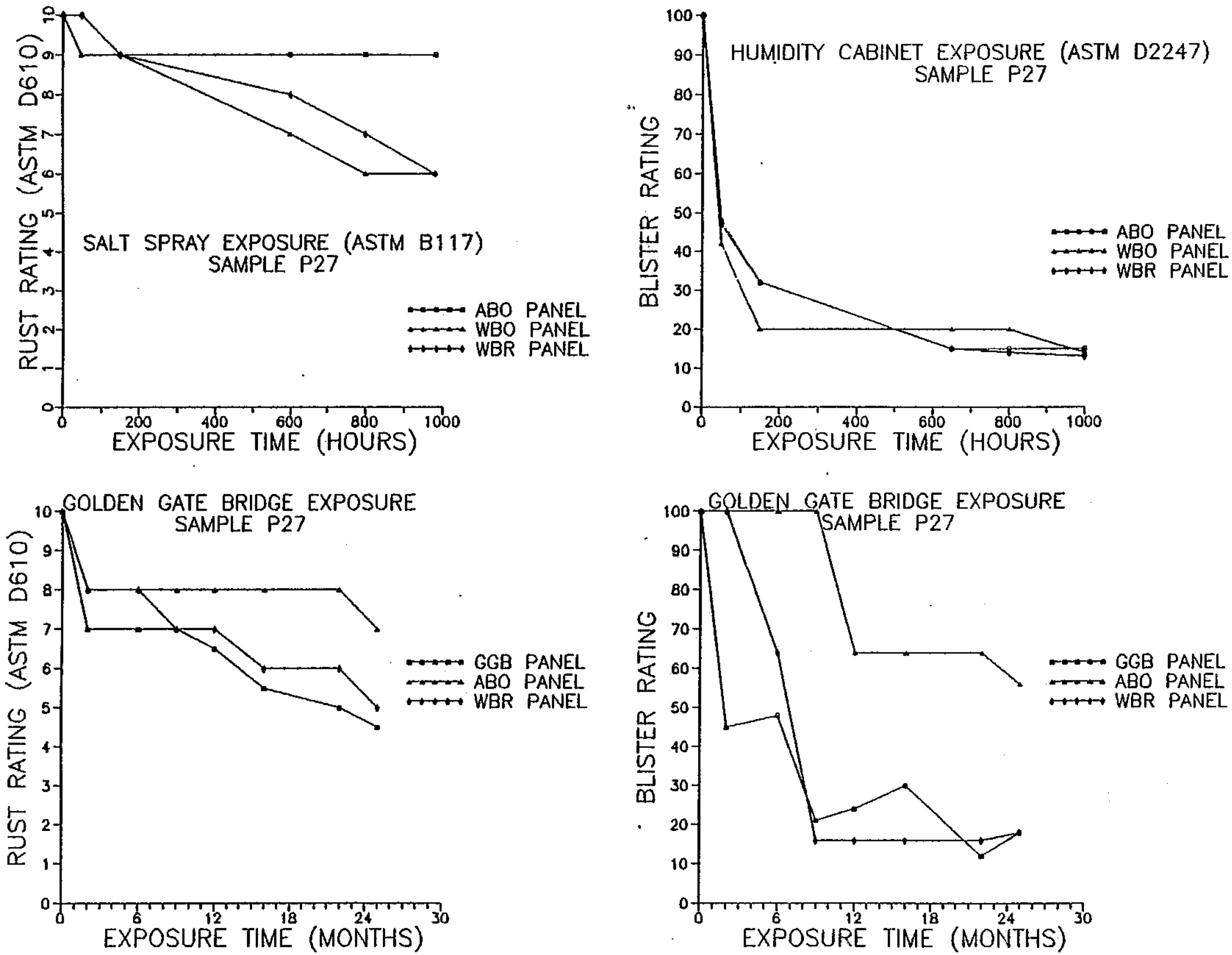
WBO PANEL
WBR PANEL
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P25
BLISTER RATING
EXPOSURE TIME (HOURS)
ABO PANEL
WBO PANEL
WBR PANEL
PRETREATMENT P25
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P25
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P25
BLISTER RATING
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL

FIGURE II

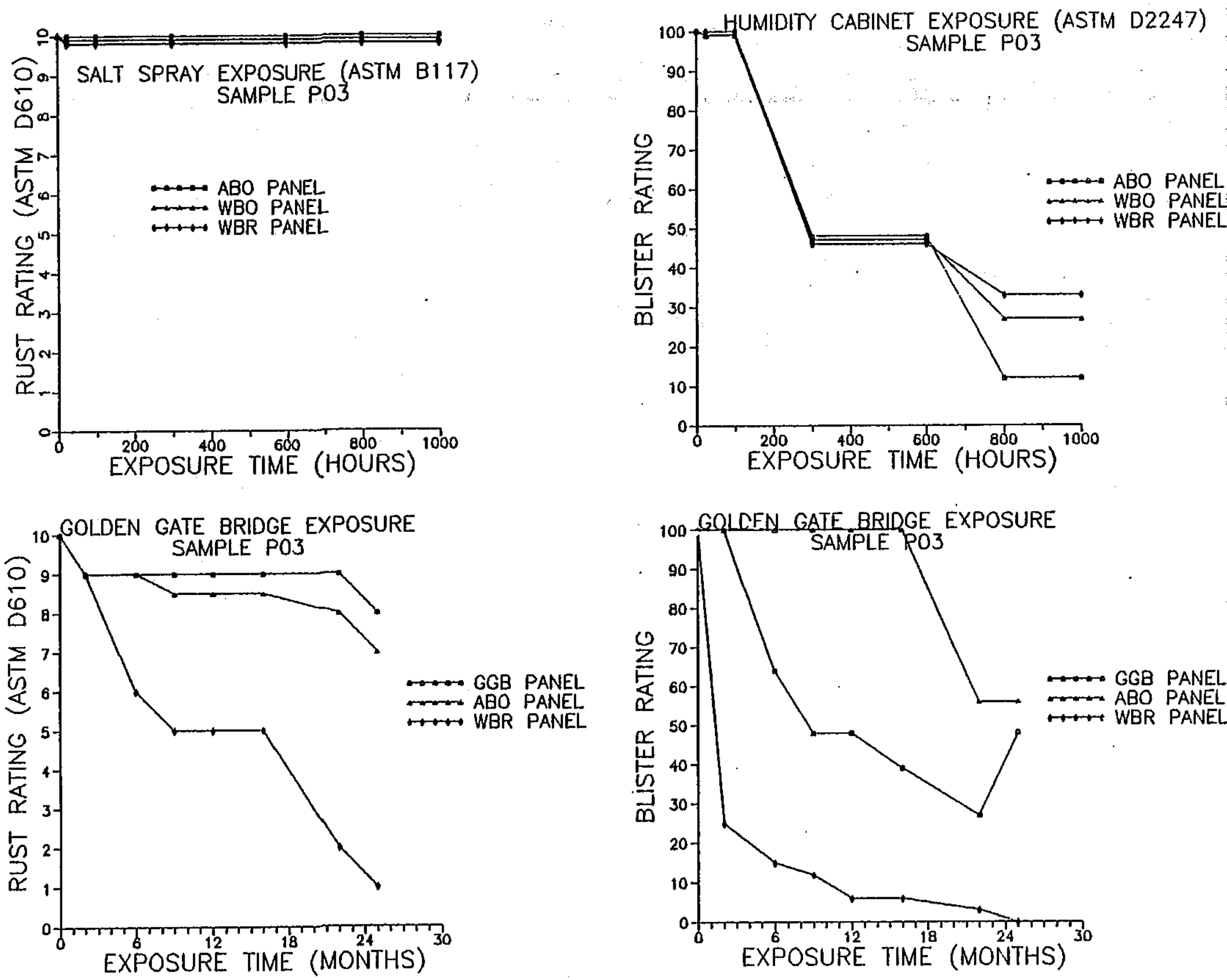
PRETREATMENT P27



PRETREATMENT P27

FIGURE III

RUST CONVERTER P03



RUST CONVERTER P03

FIGURE IV

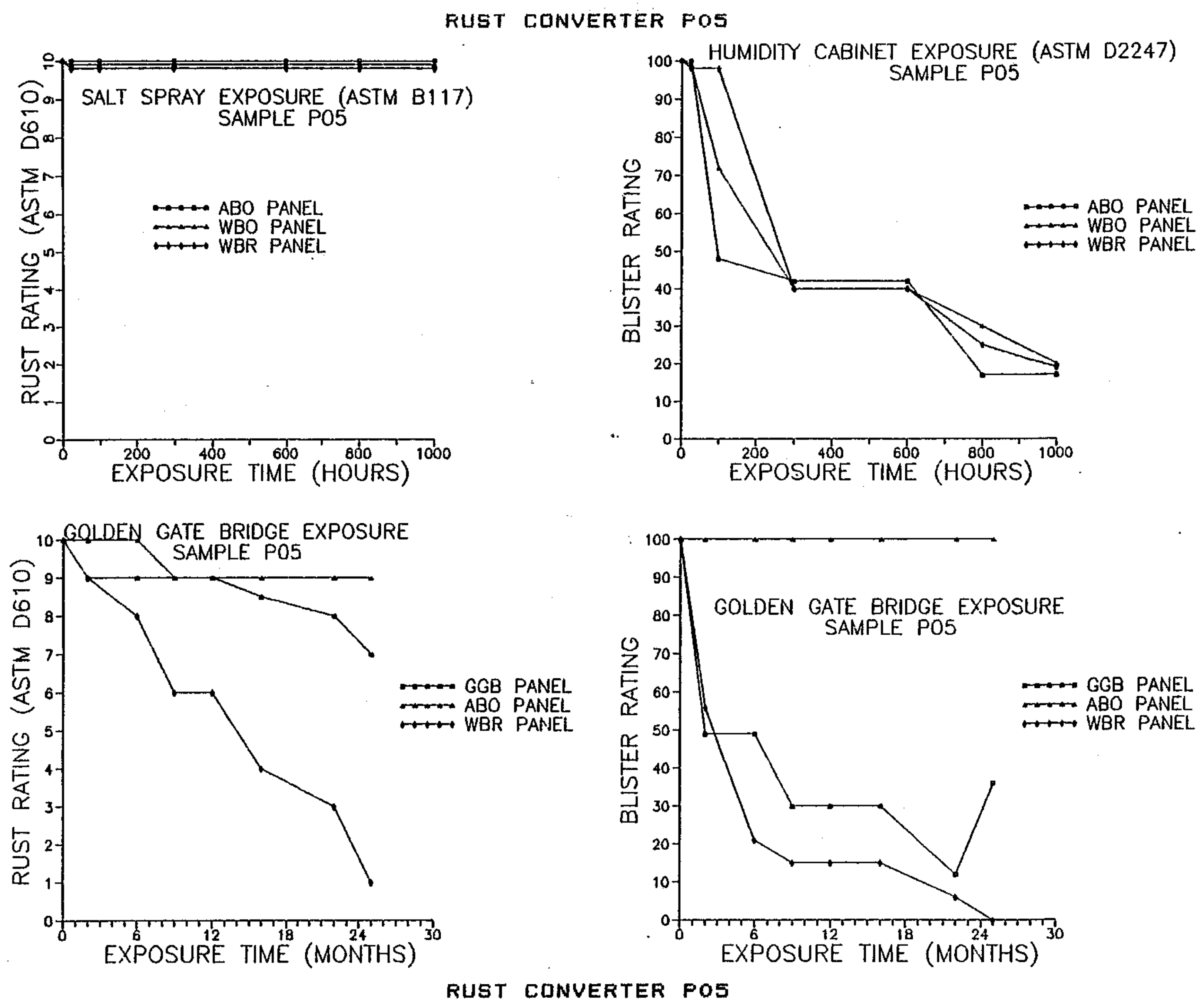

RUST CONVERTER P05
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P05
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
ABO PANEL
WBO PANEL
WBR PANEL
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P05
BLISTER RATING
EXPOSURE TIME (HOURS)
ABO PANEL
WBO PANEL
WBR PANEL
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P05
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P05
BLISTER RATING
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL
RUST CONVERTER P05

FIGURE V

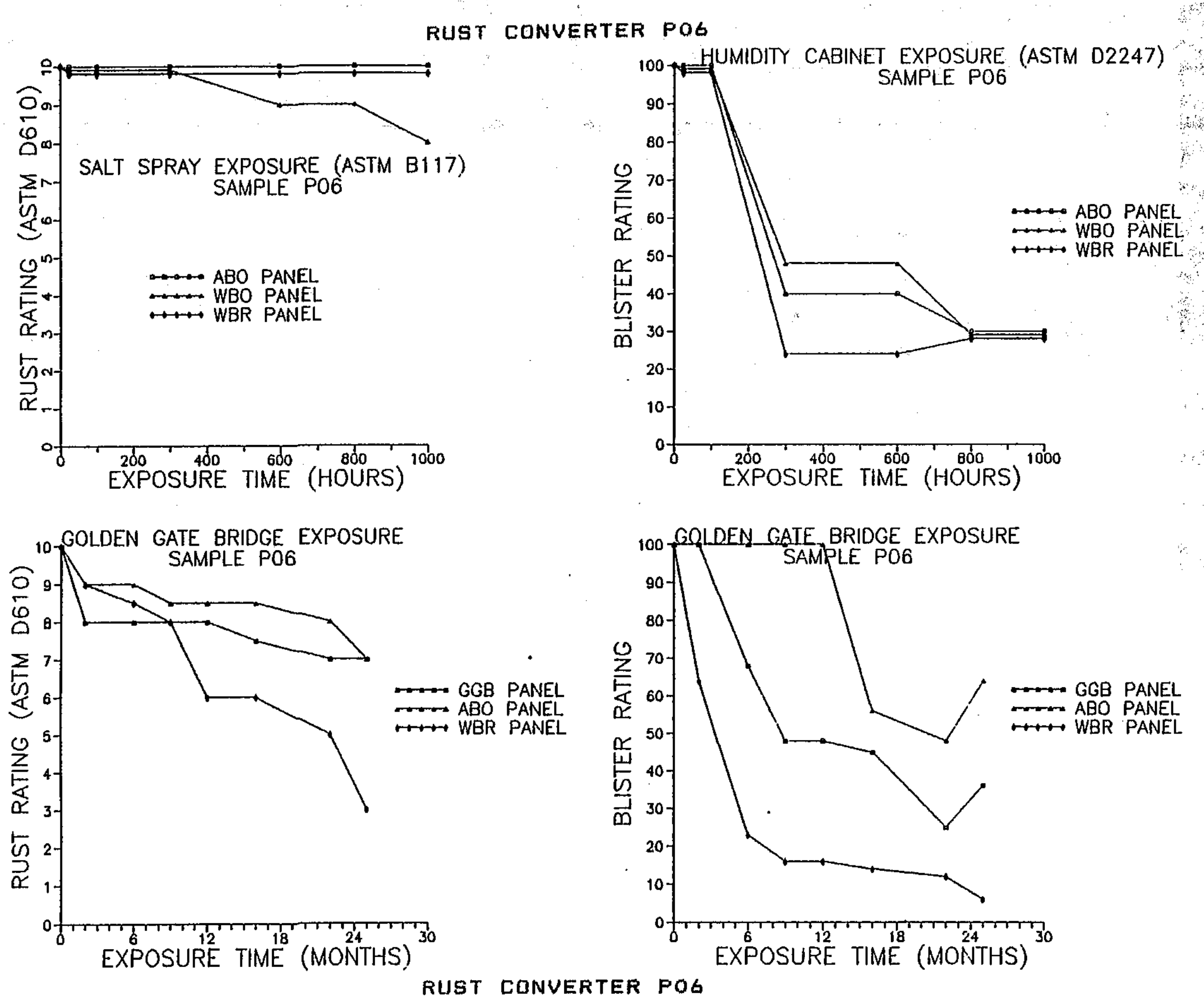
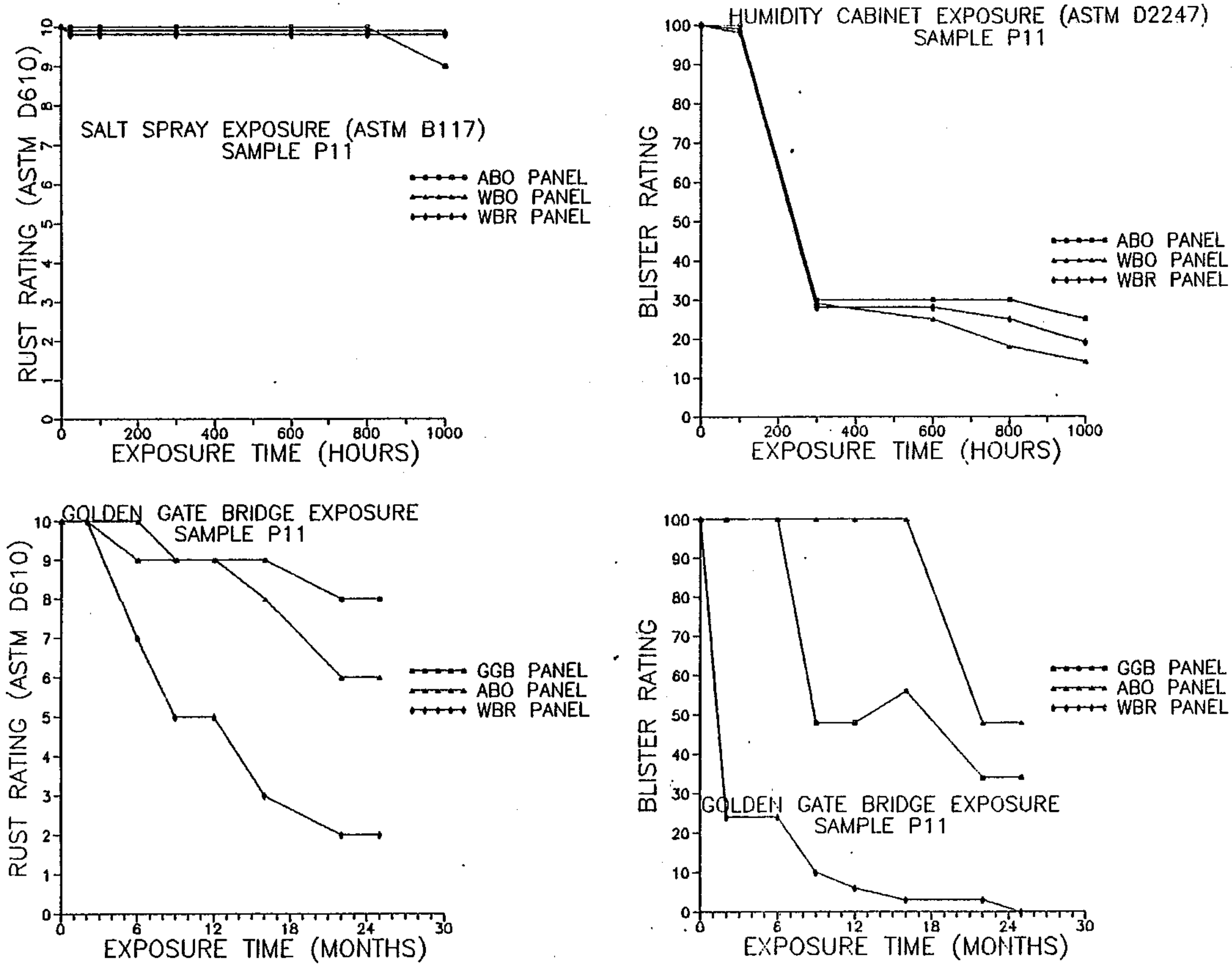

RUST CONVERTER P06
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P06
RUST RATING (ASTM D610)
ABO PANEL
WBO PANEL
WBR PANEL
EXPOSURE TIME (HOURS)
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P06
BLISTER RATING
ABO PANEL
WBO PANEL
WBR PANEL
EXPOSURE TIME (HOURS)
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P06
RUST RATING (ASTM D610)
GGB PANEL
ABO PANEL
WBR PANEL
EXPOSURE TIME (MONTHS)
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P06
BLISTER RATING
GGB PANEL
ABO PANEL
WBR PANEL
EXPOSURE TIME (MONTHS)
RUST CONVERTER P06

FIGURE VI

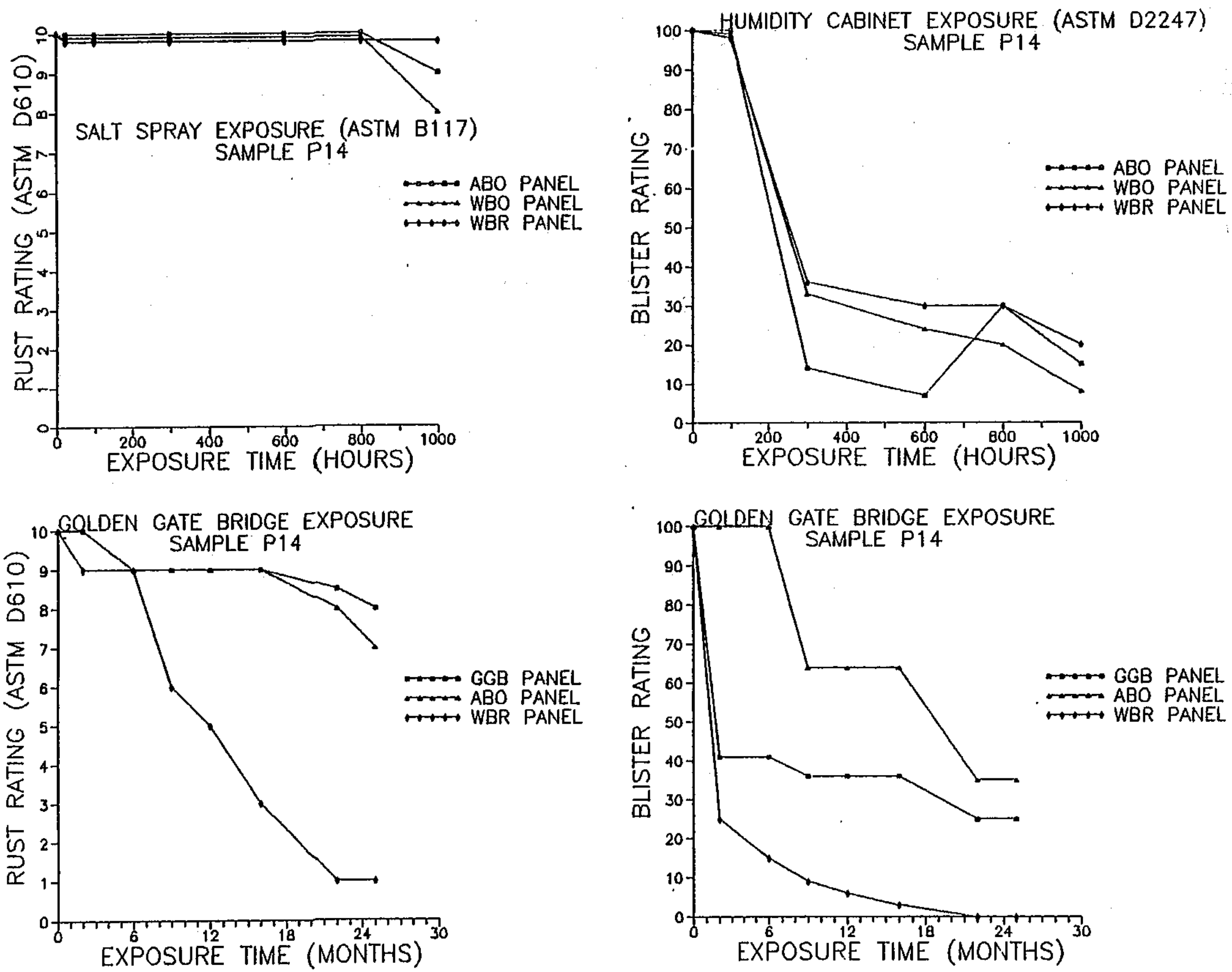
RUST CONVERTER P11



RUST CONVERTER P11

FIGURE VII

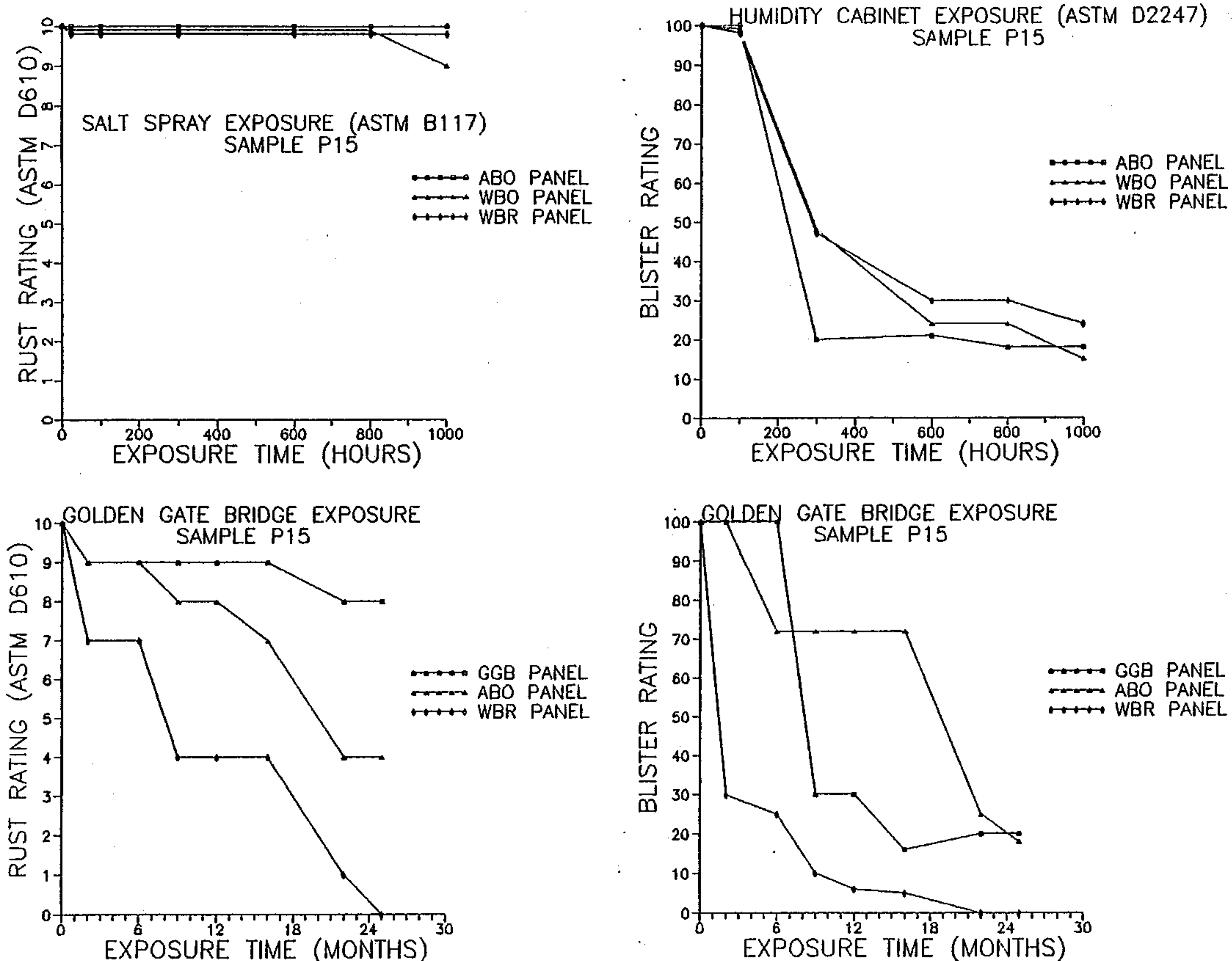
RUST CONVERTER P14



RUST CONVERTER P14

FIGURE VIII

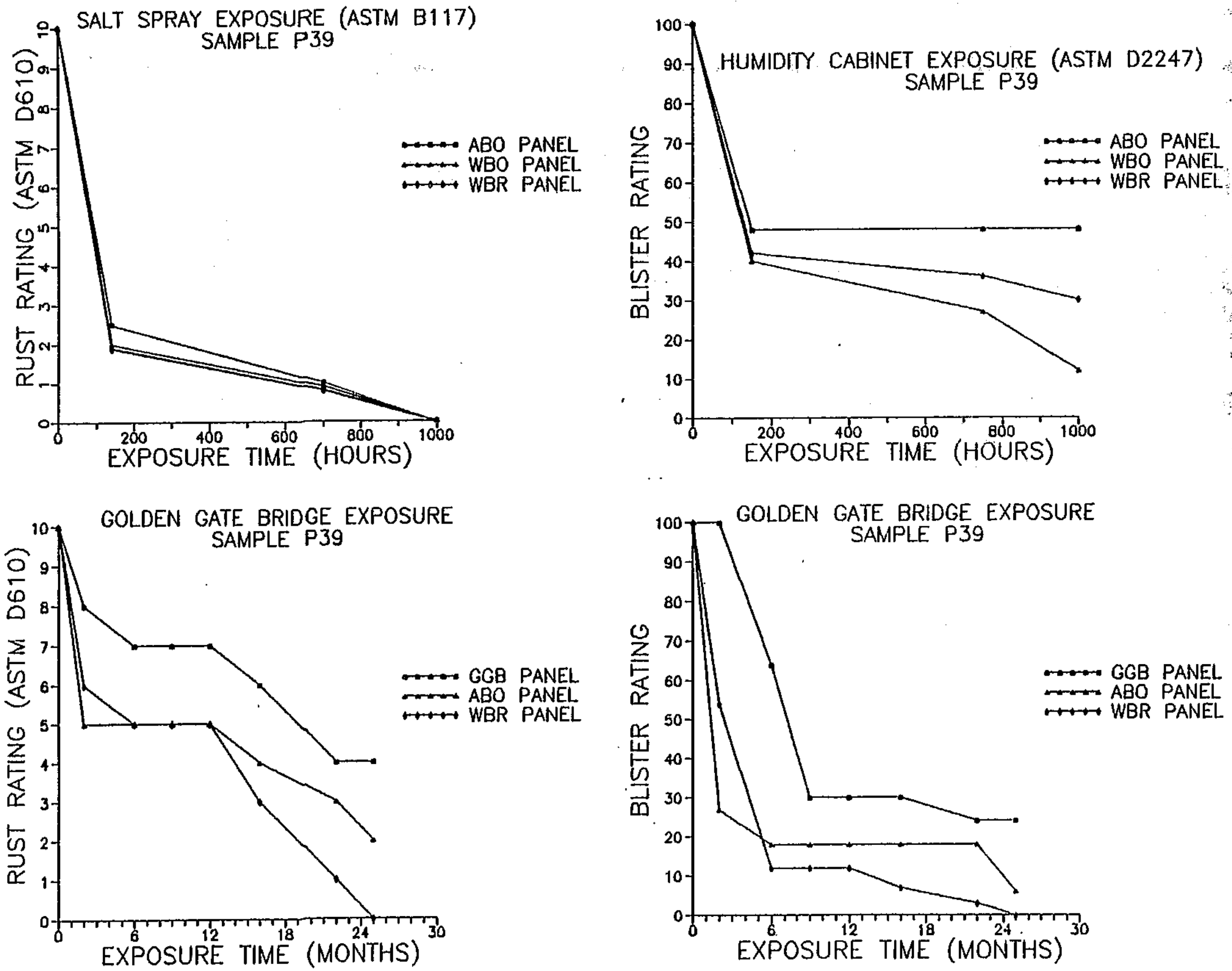
RUST CONVERTER P15



RUST CONVERTER P15

FIGURE IX

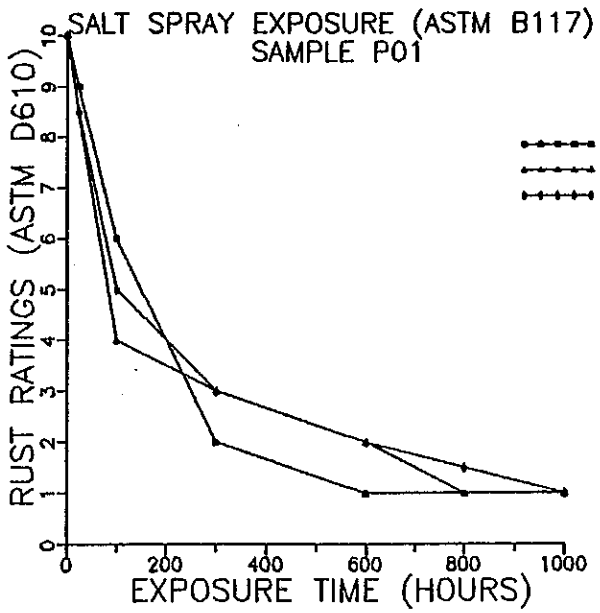
RUST CONVERTER P39

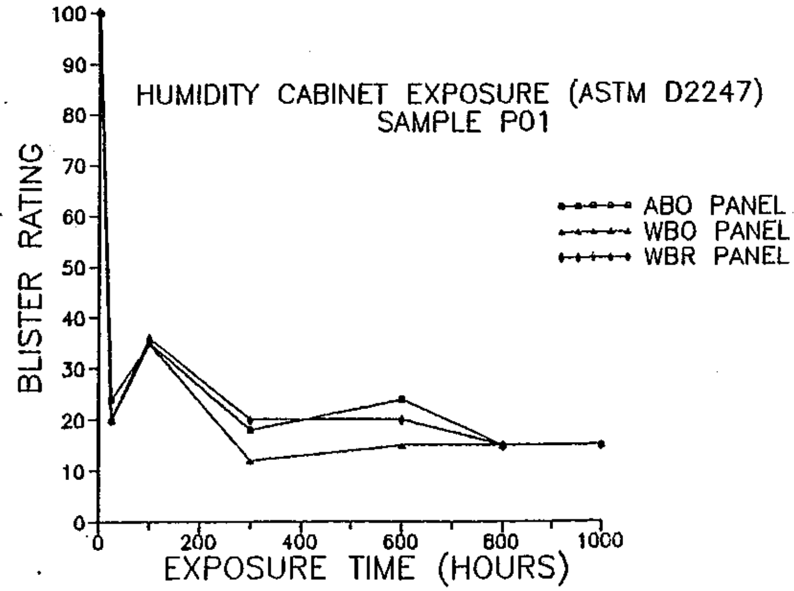


RUST CONVERTER P39

FIGURE X

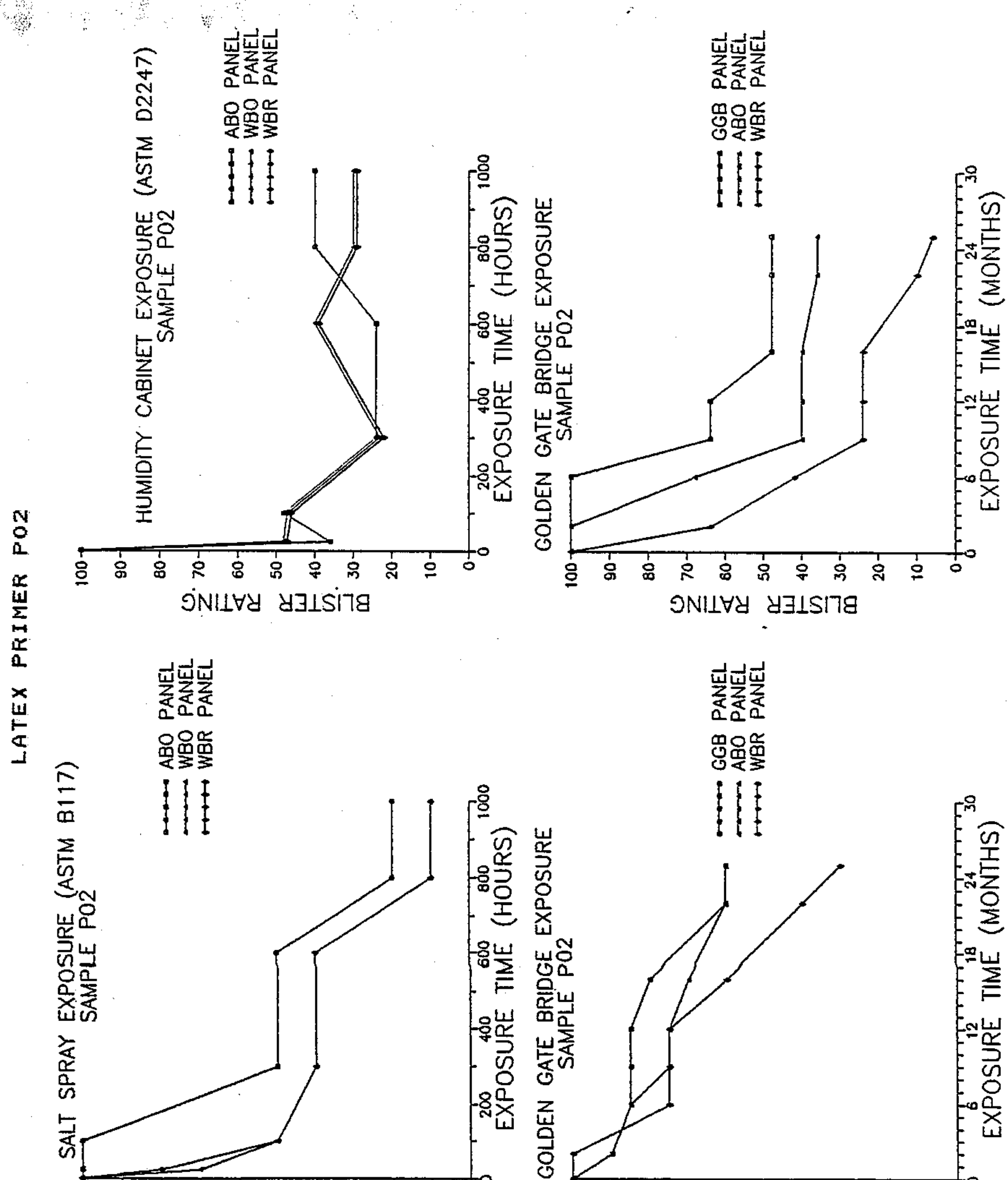
LATEX PRIMER P01





LATEX PRIMER P01

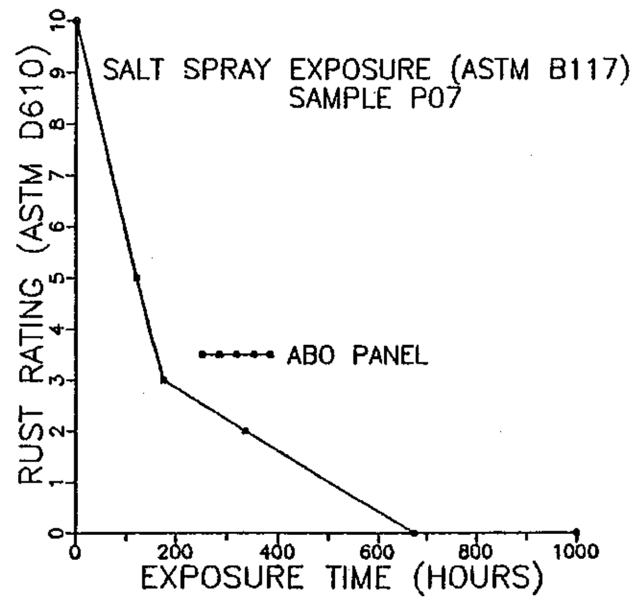
FIGURE XI

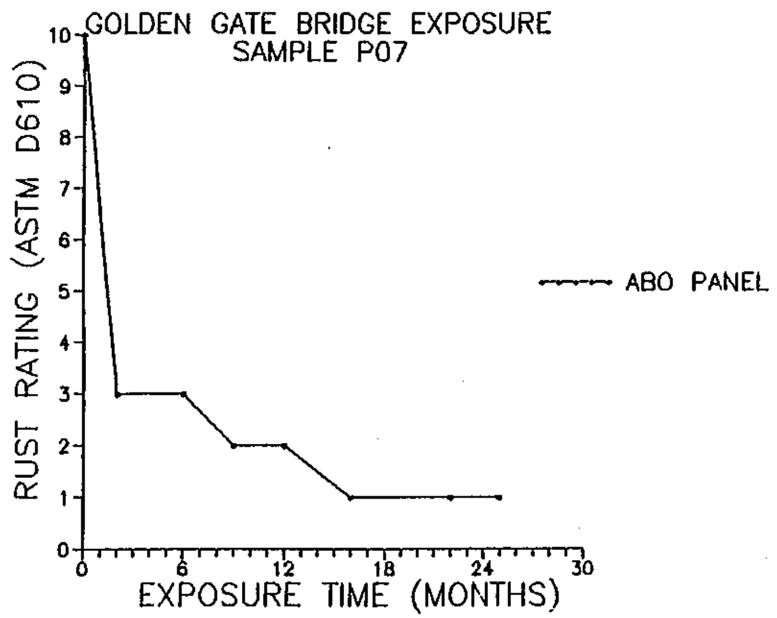


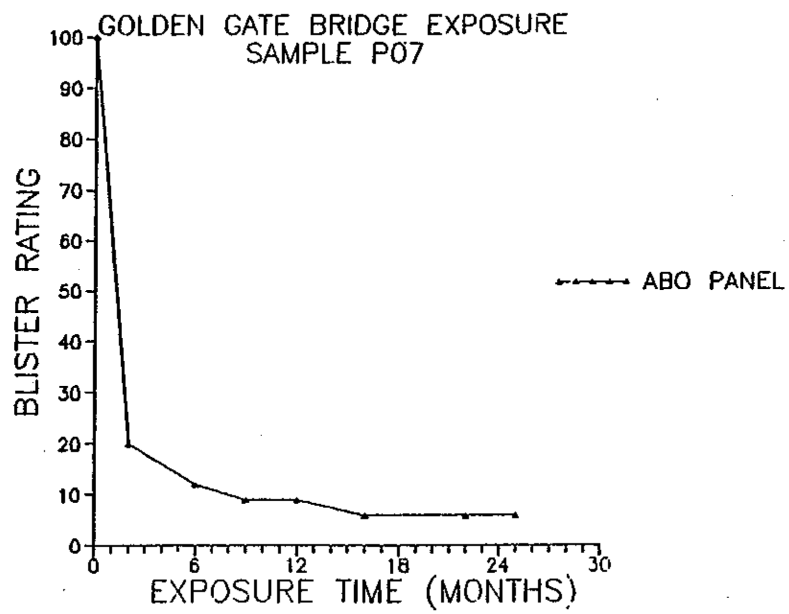
LATEX PRIMER P02
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P02
ABO PANEL
WBO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P02
BLISTER RATING
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P02
GGB PANEL
EXPOSURE TIME (MONTHS)
LATEX PRIMER P02

FIGURE XII

LATEX PRIMER P07



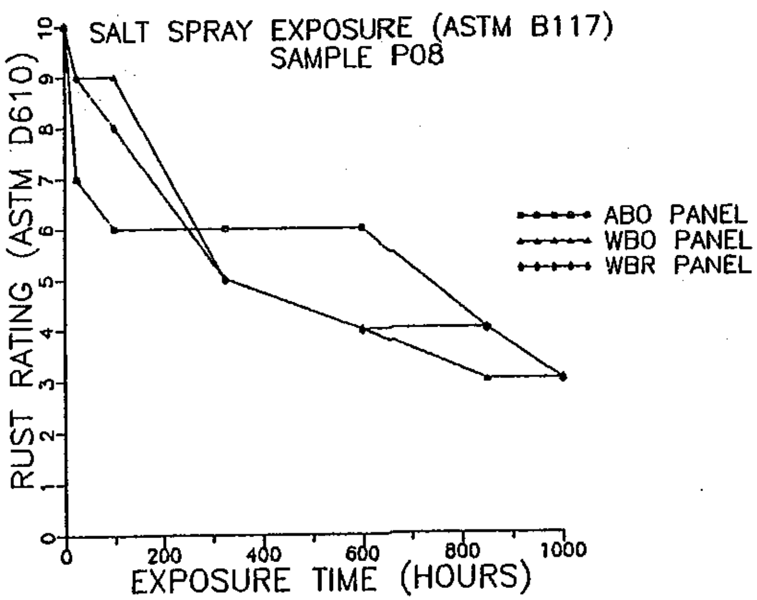


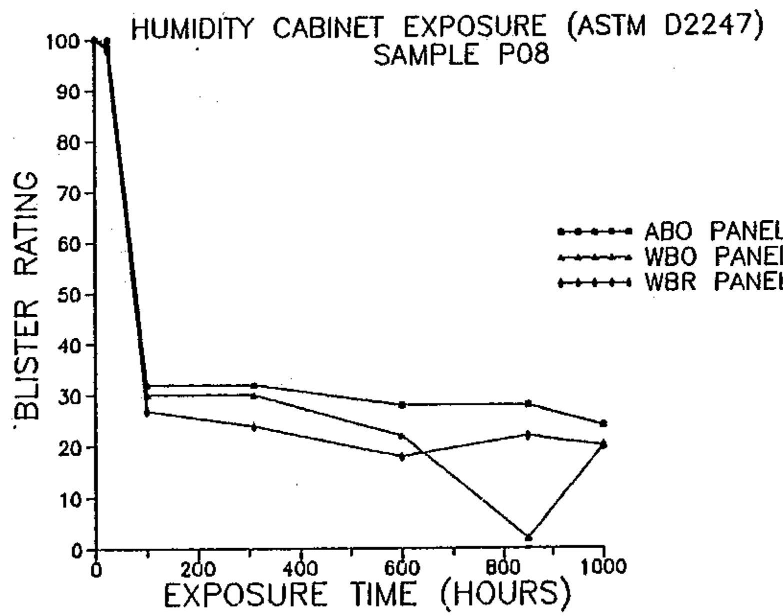


LATEX PRIMER P07

FIGURE XIII

CEMENTITIOUS PAINT P08

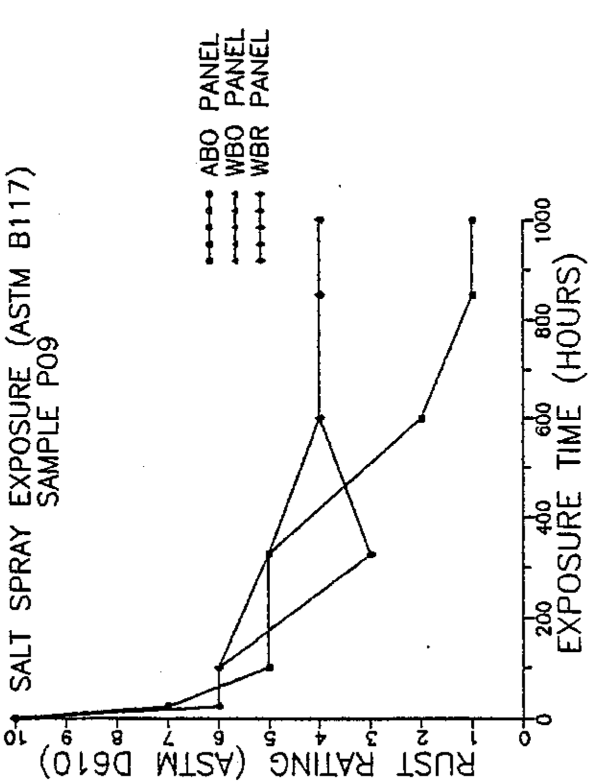


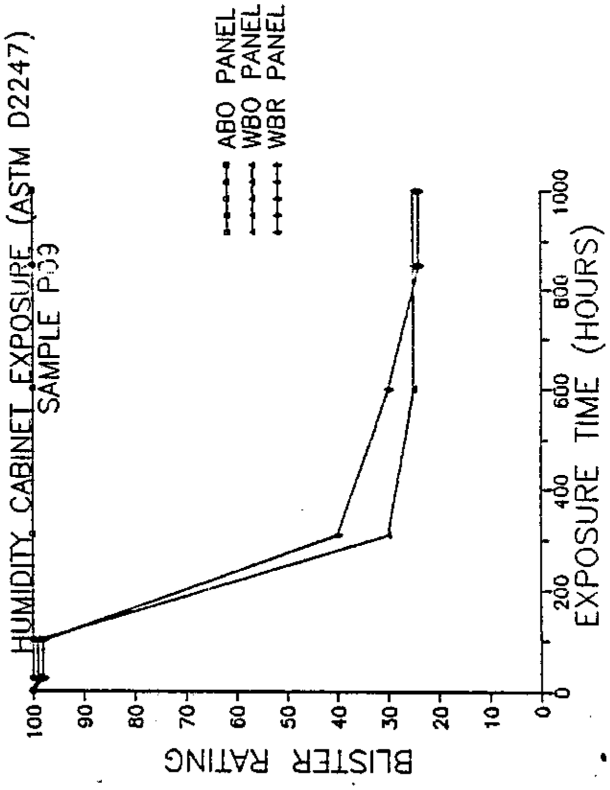


CEMENTITIOUS PAINT P08

FIGURE XIV

CEMENTITIOUS PAINT P09

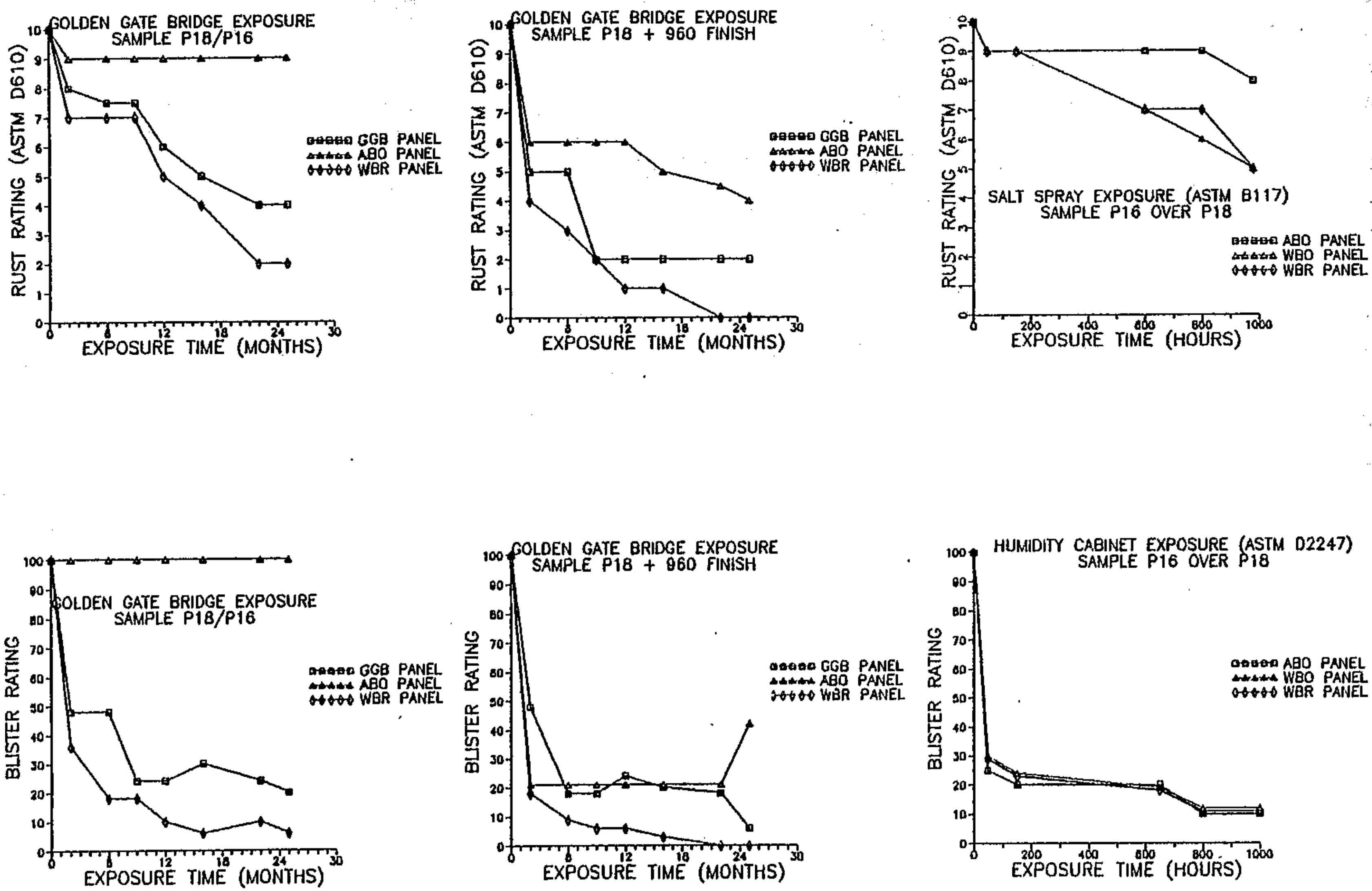




CEMENTITIOUS PAINT P09

FIGURE XV

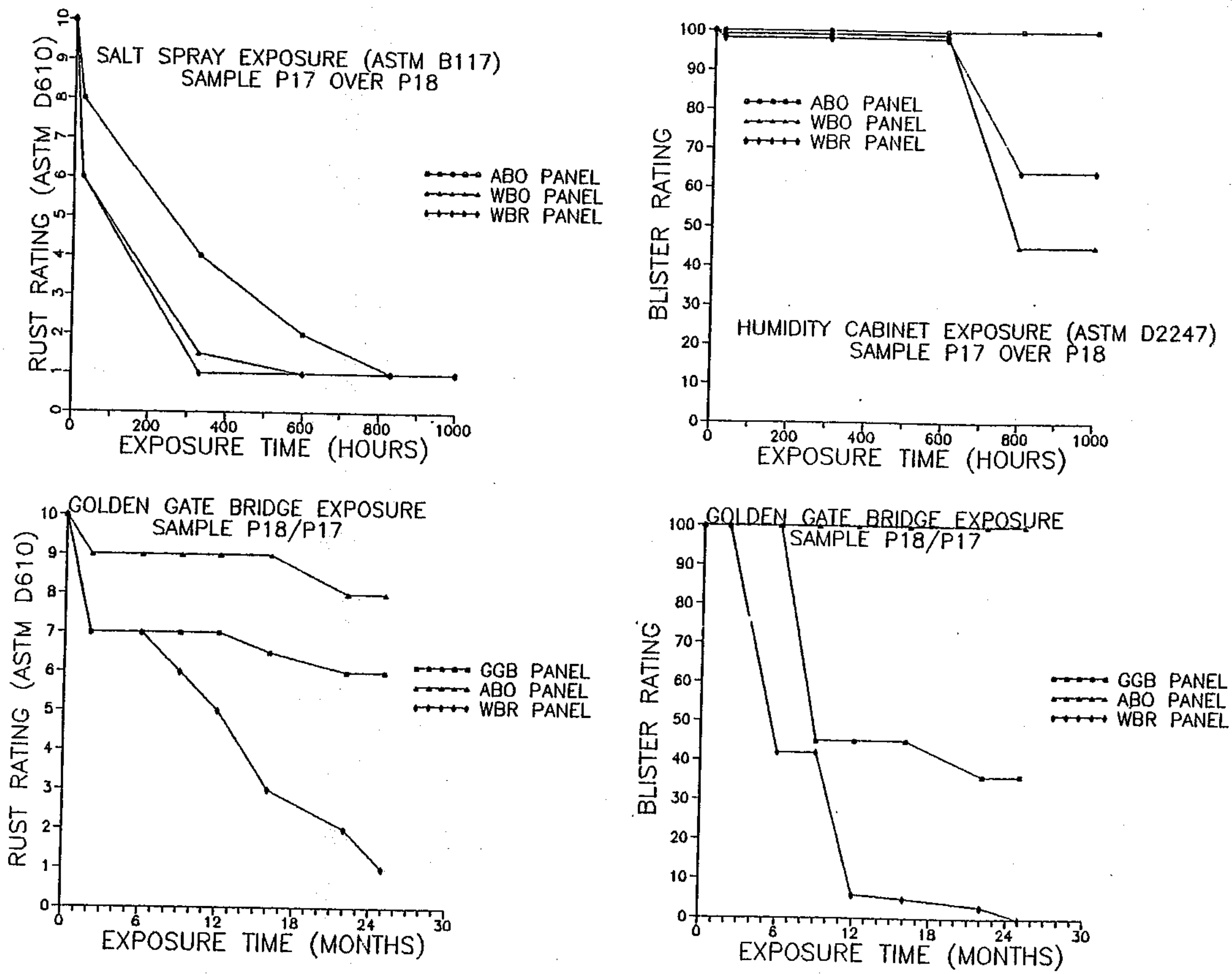
LATEX SYSTEMS; P18 PRIME + P16 OR 960 FINISH



LATEX SYSTEMS; P18 PRIME + P16 OR 960 FINISH

FIGURE XVI

LATEX SYSTEMS; P18 PRIME + P17 FINISH



LATEX SYSTEMS; P18 PRIME + P17 FINISH

FIGURE XVII

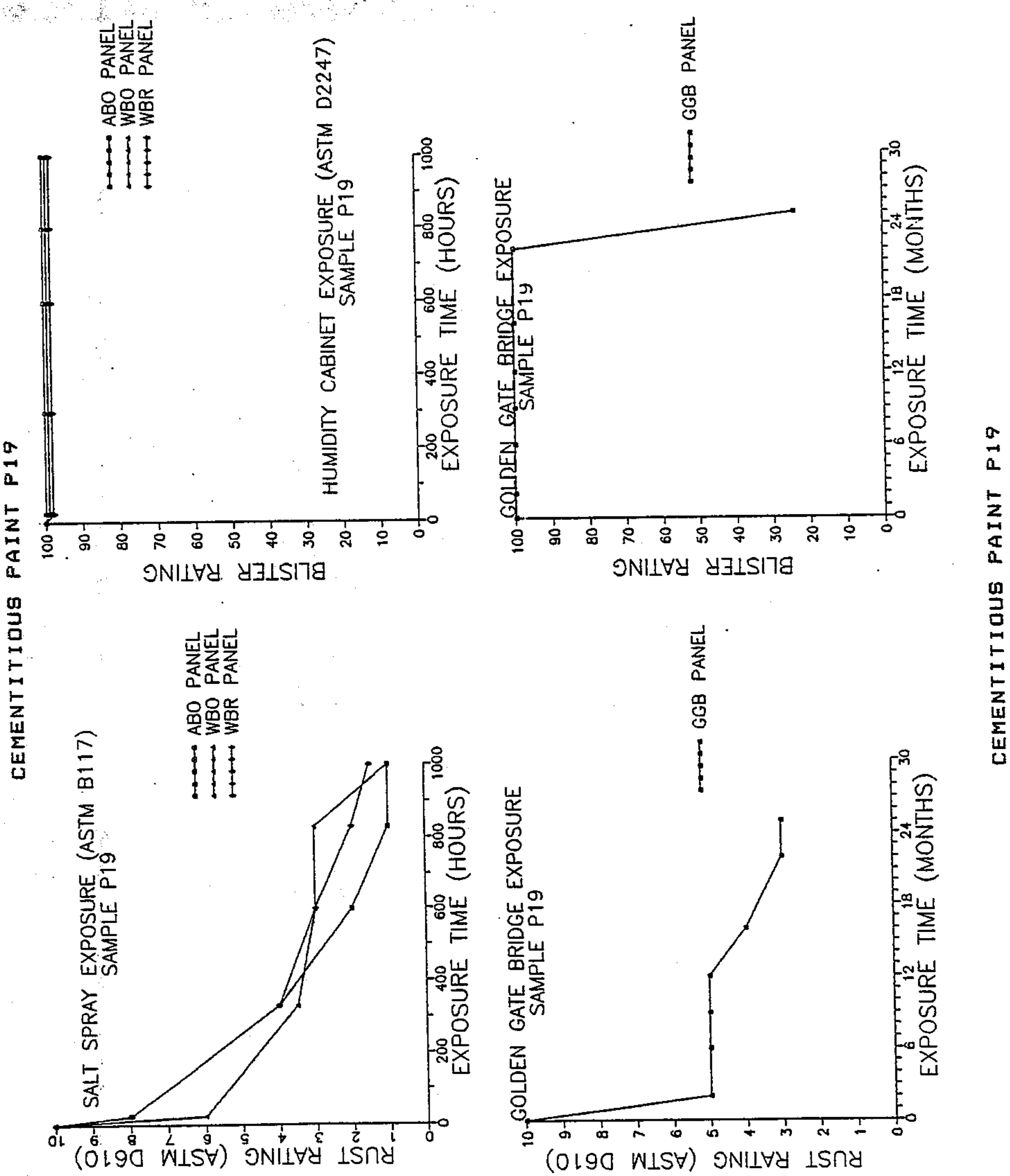
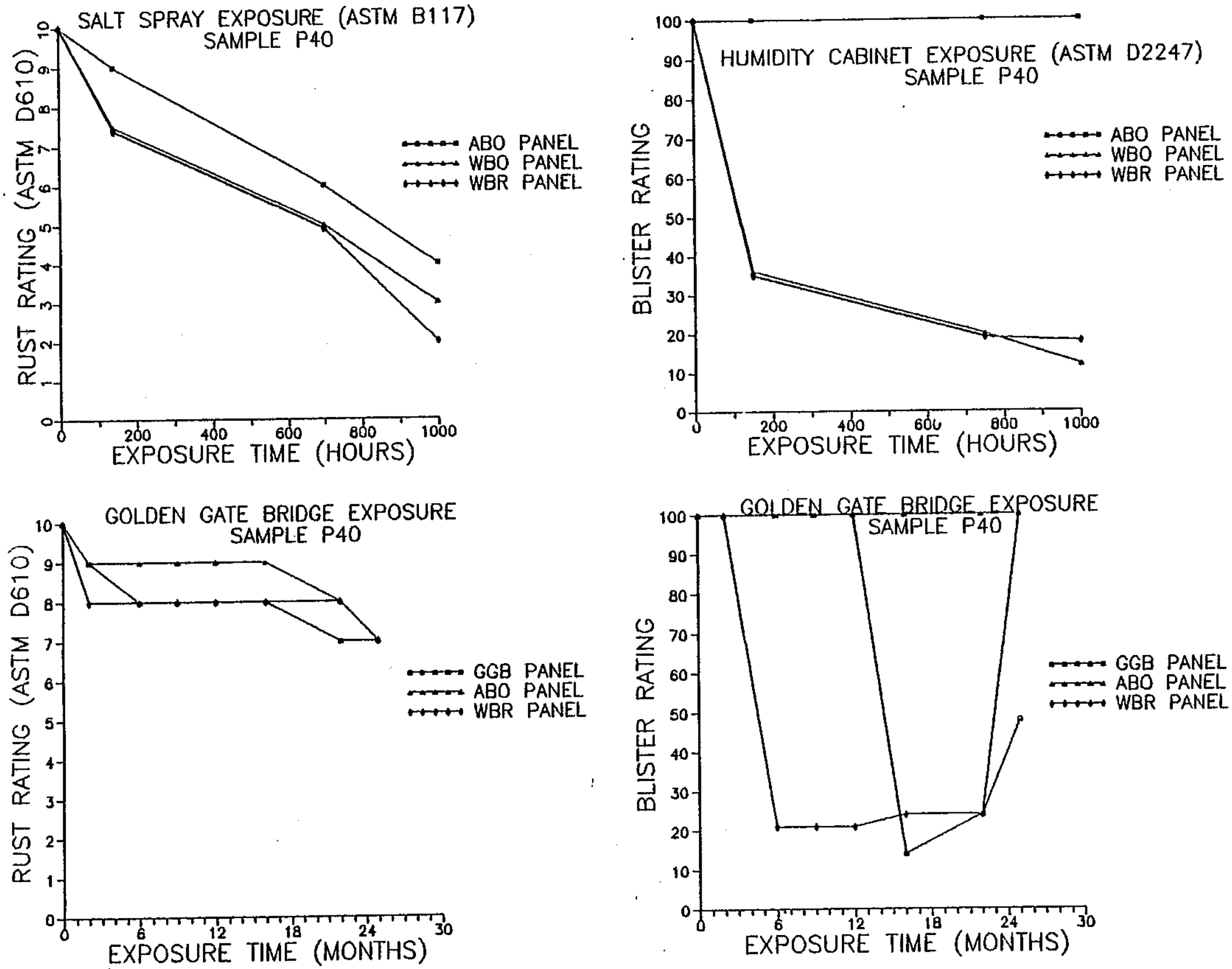


FIGURE XVIII

LATEX PRIMER P40



LATEX PRIMER P40

FIGURE XIX

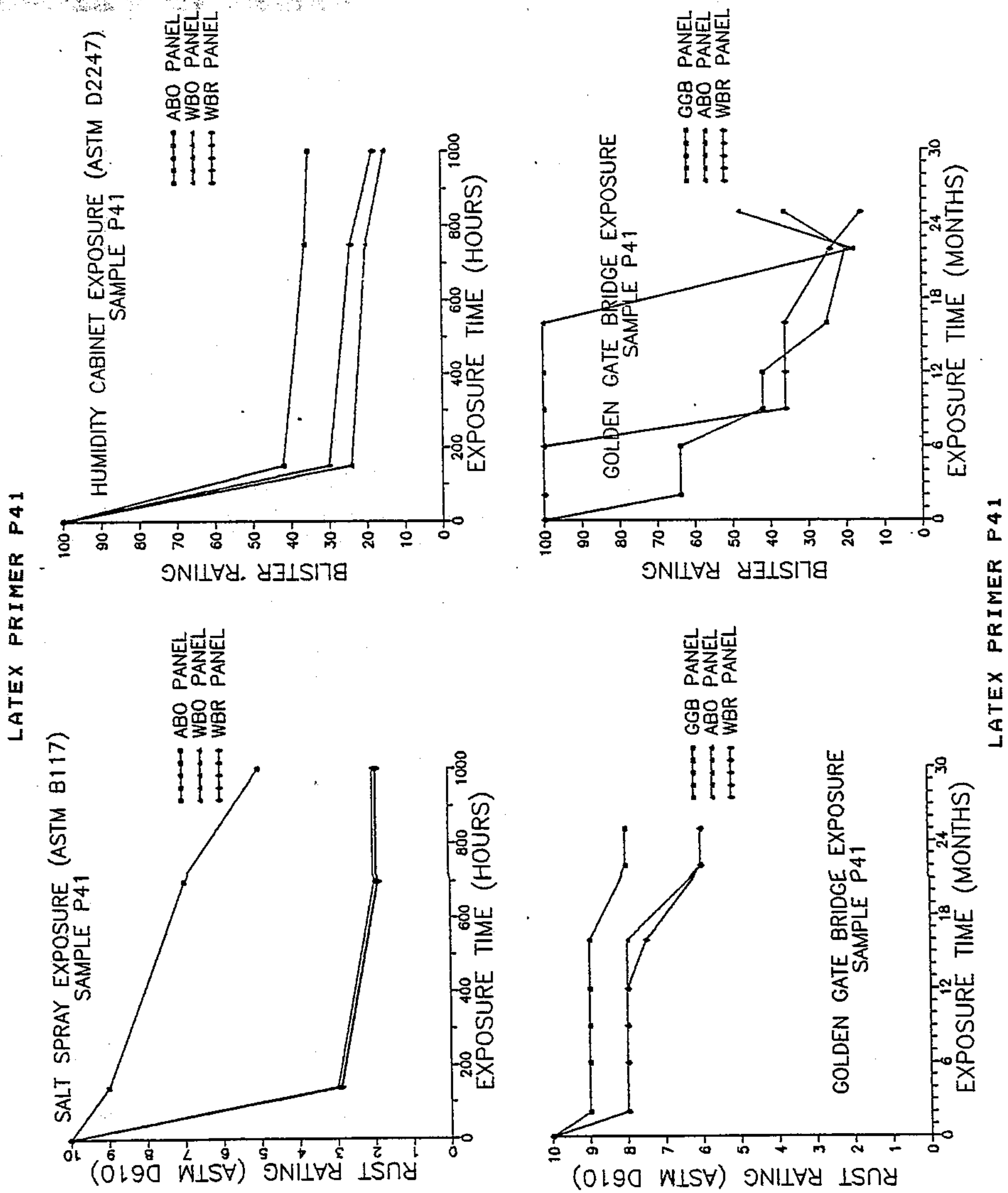
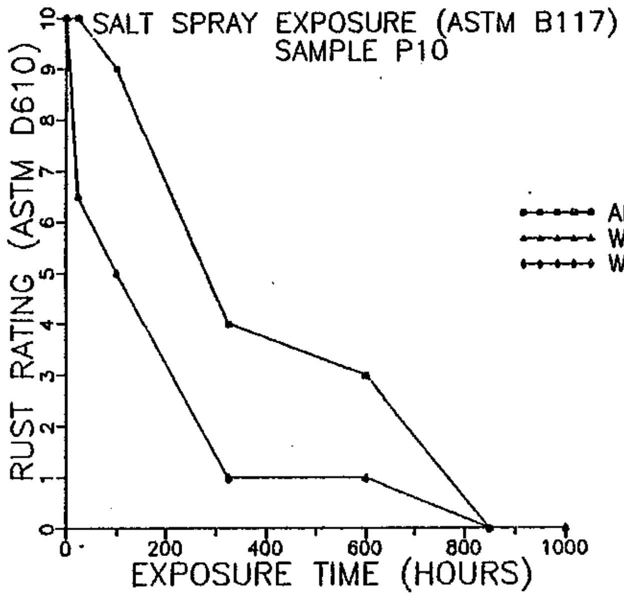
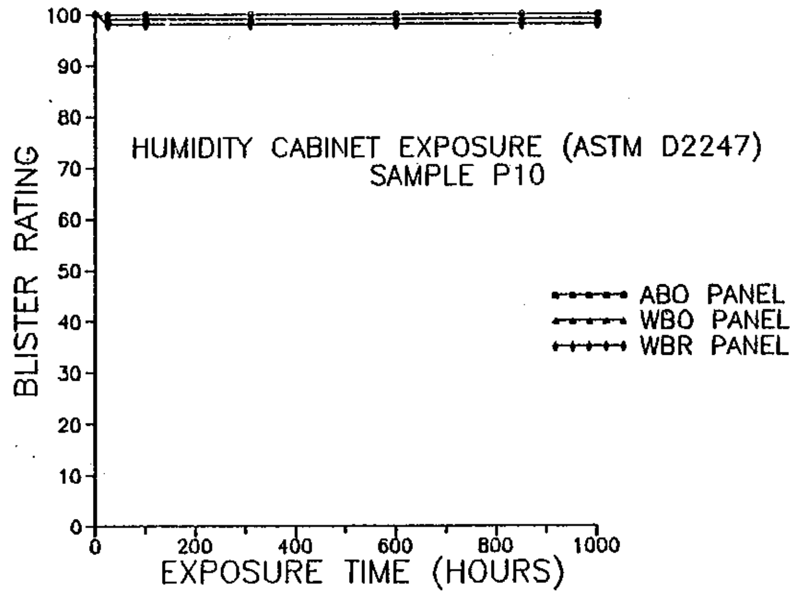

LATEX PRIMER P41
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P41
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
ABO PANEL
WBO PANEL
WBR PANEL
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P41
BLISTER RATING
EXPOSURE TIME (HOURS)
ABO PANEL
WBO PANEL
WBR PANEL
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P41
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P41
BLISTER RATING
EXPOSURE TIME (MONTHS)
GGB PANEL
ABO PANEL
WBR PANEL
LATEX PRIMER P41

FIGURE XX

NONHARDENING WAX P10

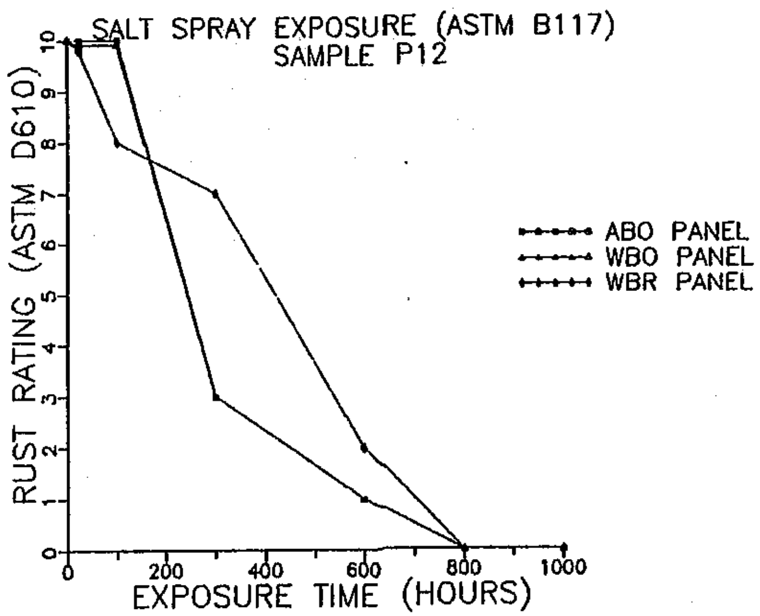


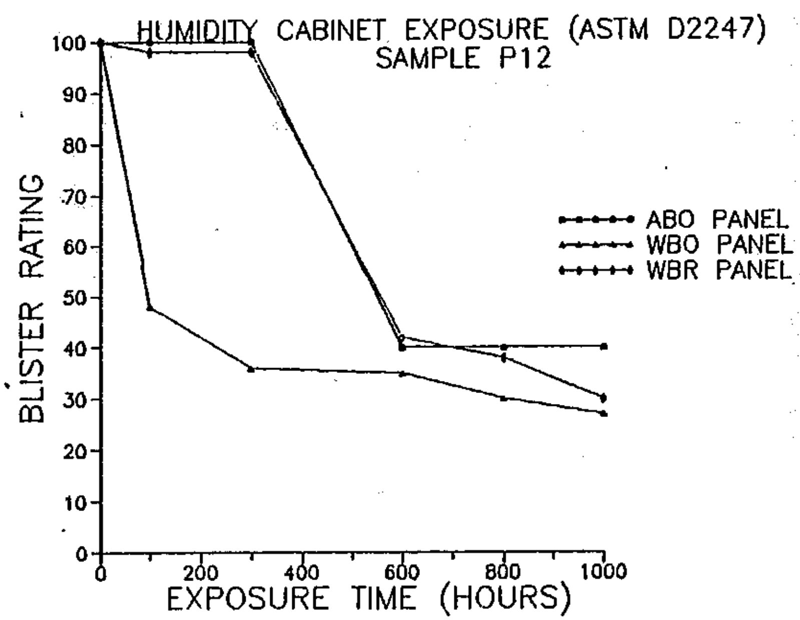


NONHARDENING WAX P10

FIGURE XXI

NONHARDENING WAX P12

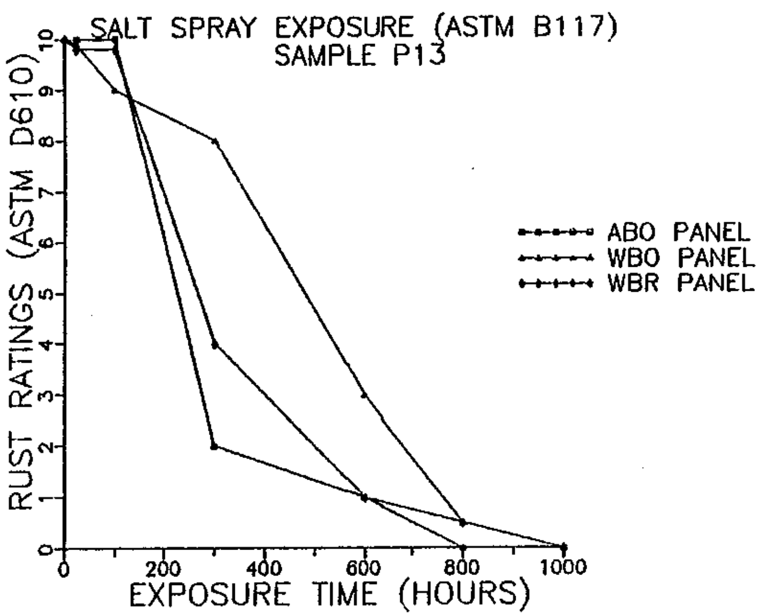


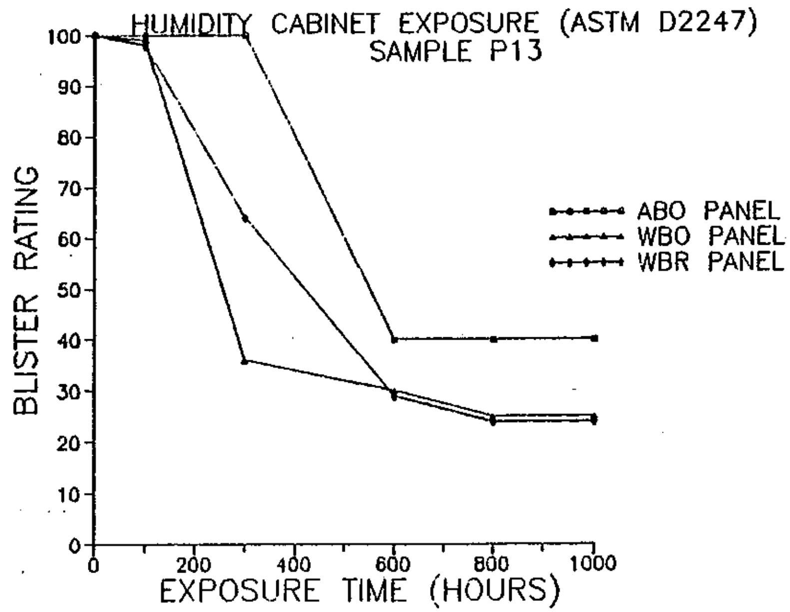


NONHARDENING WAX P12

FIGURE XXII

NONHARDENING WAX P13

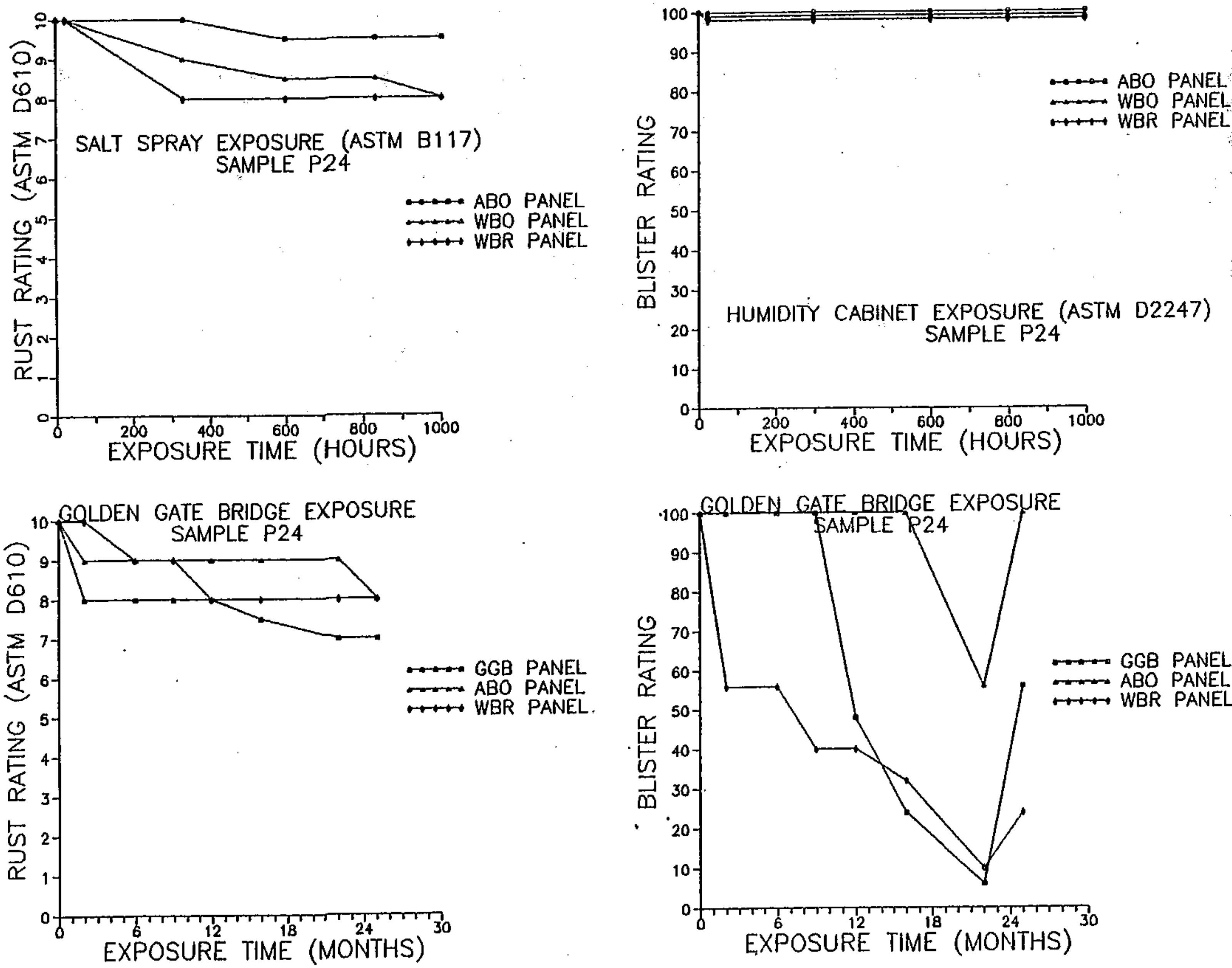




NONHARDENING WAX P13

FIGURE XXIII

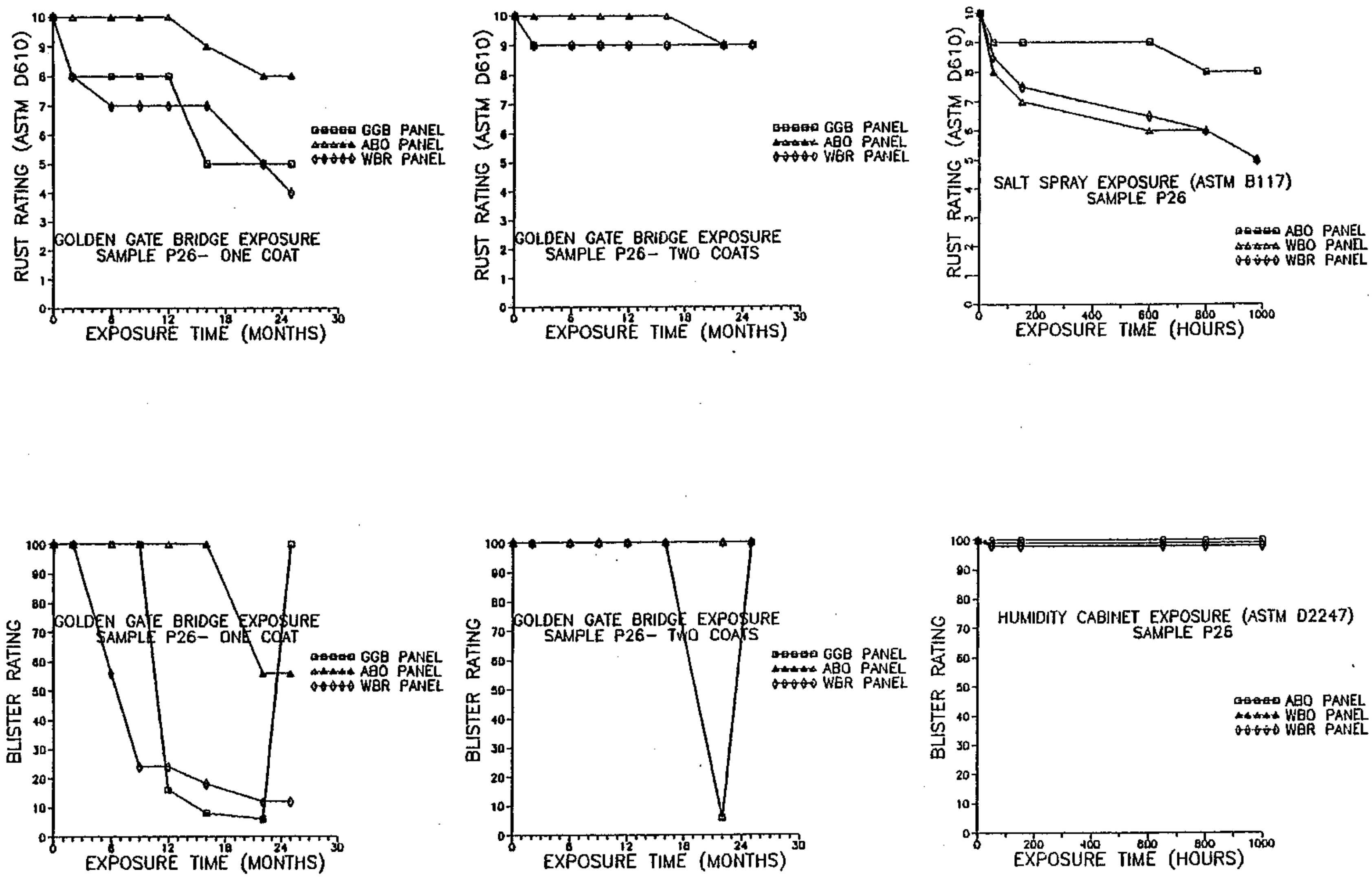
EPOXY MASTIC P24



EPOXY MASTIC P24

FIGURE XXIV

EPOXY MASTIC P26



EPOXY MASTIC P26

FIGURE XXV

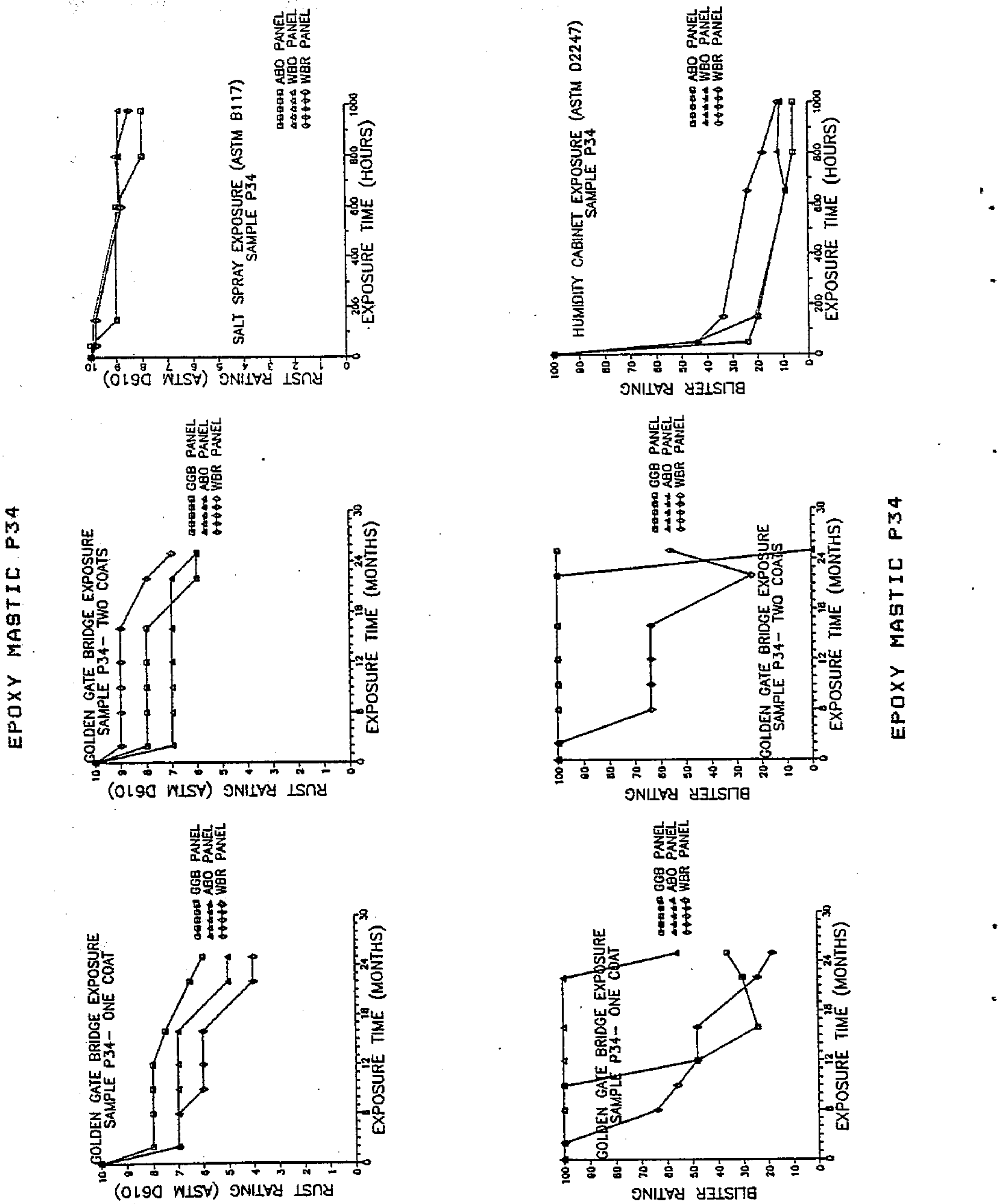
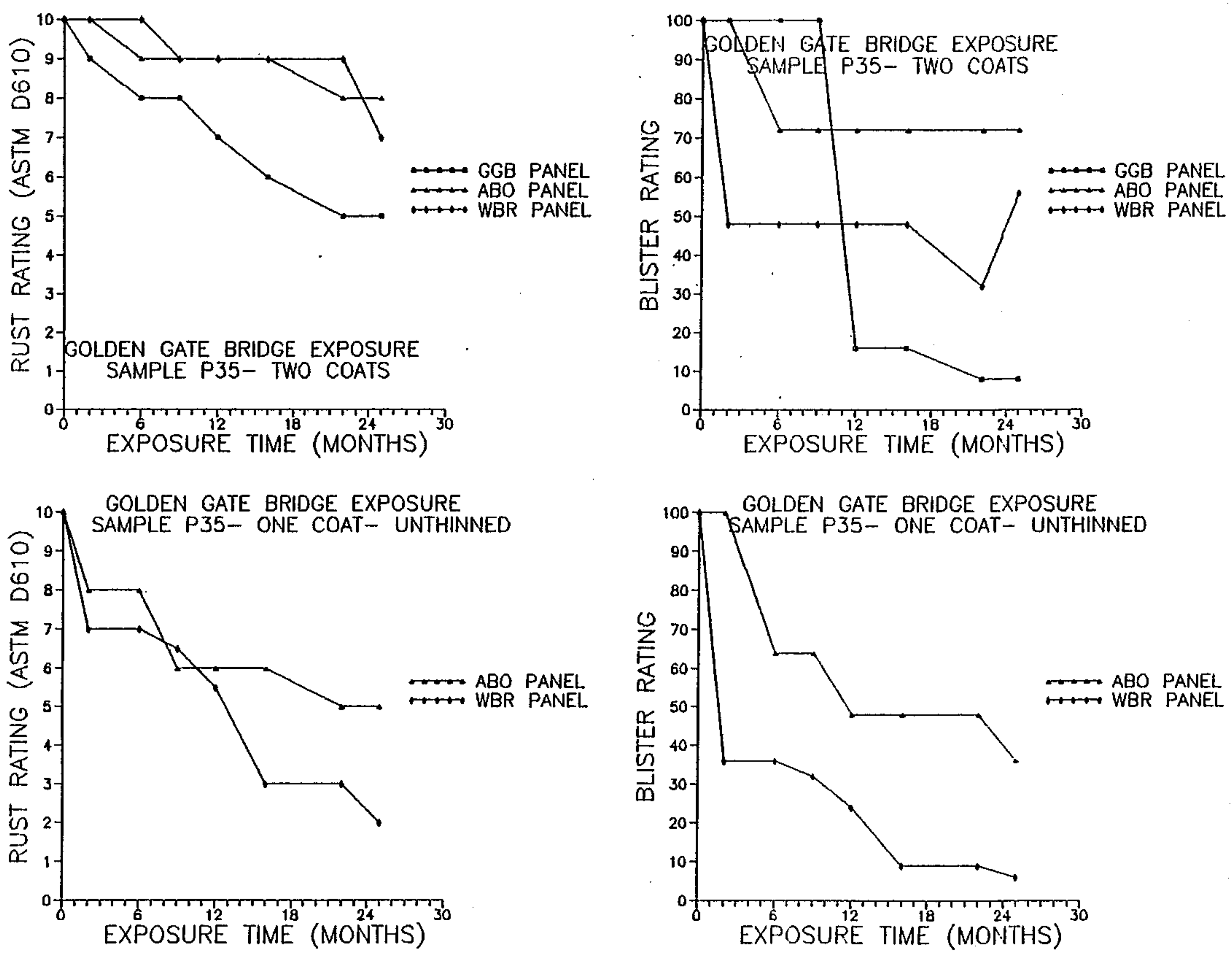

EPOXY MASTIC P34
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P34- ONE COAT
GGB PANEL
ABO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P34- TWO COATS
GGB PANEL
ABO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (MONTHS)
SALT SPRAY EXPOSURE (ASTM B117)
SAMPLE P34
ABO PANEL
WBO PANEL
WBR PANEL
RUST RATING (ASTM D610)
EXPOSURE TIME (HOURS)
EPOXY MASTIC P34
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P34- ONE COAT
GGB PANEL
ABO PANEL
WBR PANEL
BLISTER RATING
EXPOSURE TIME (MONTHS)
GOLDEN GATE BRIDGE EXPOSURE
SAMPLE P34- TWO COATS
GGB PANEL
ABO PANEL
WBR PANEL
BLISTER RATING
EXPOSURE TIME (MONTHS)
HUMIDITY CABINET EXPOSURE (ASTM D2247)
SAMPLE P34
ABO PANEL
WBO PANEL
WBR PANEL
BLISTER RATING
EXPOSURE TIME (HOURS)

FIGURE XXVI

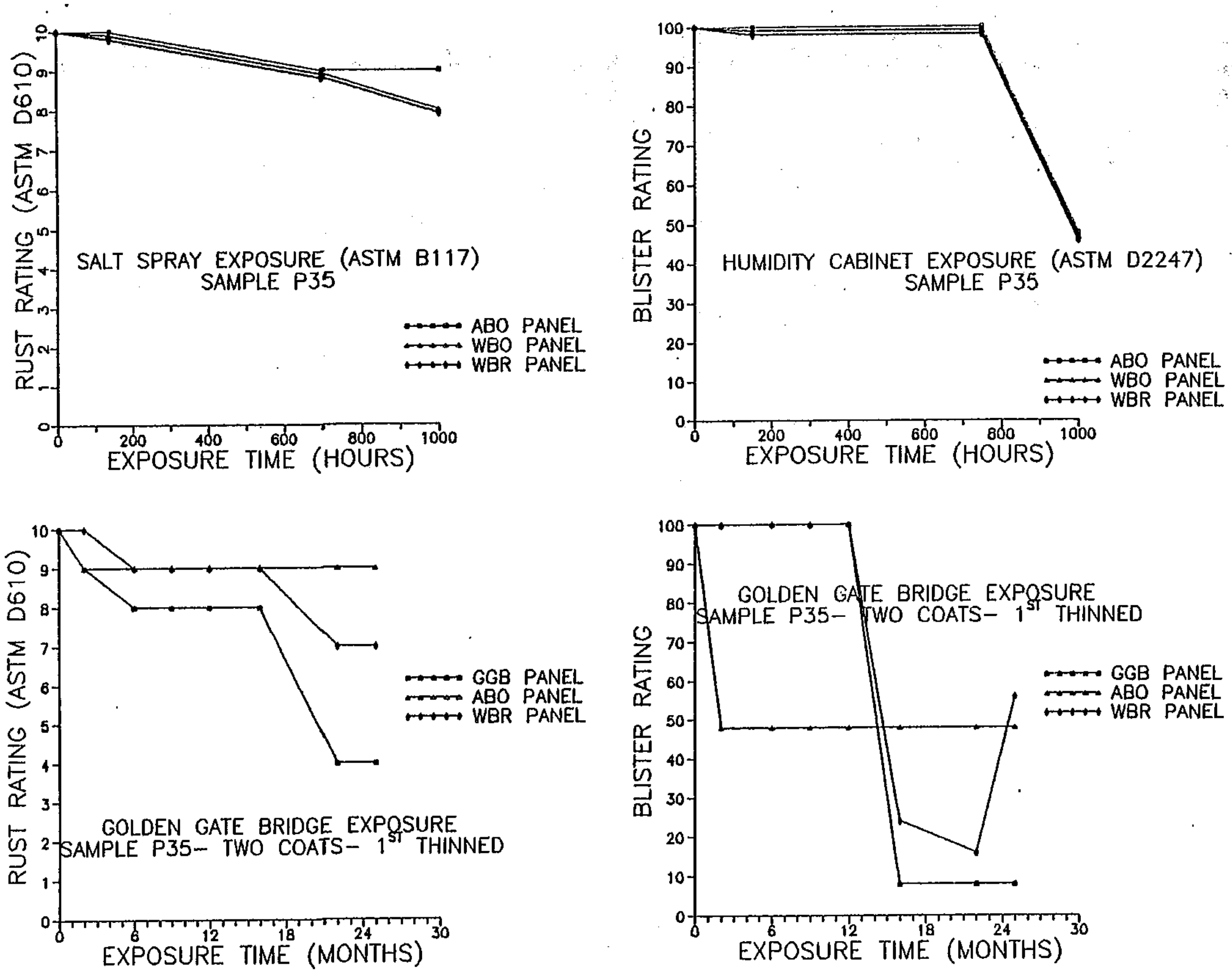
EPOXY MASTIC P35



EPOXY MASTIC P35

FIGURE XXXVII

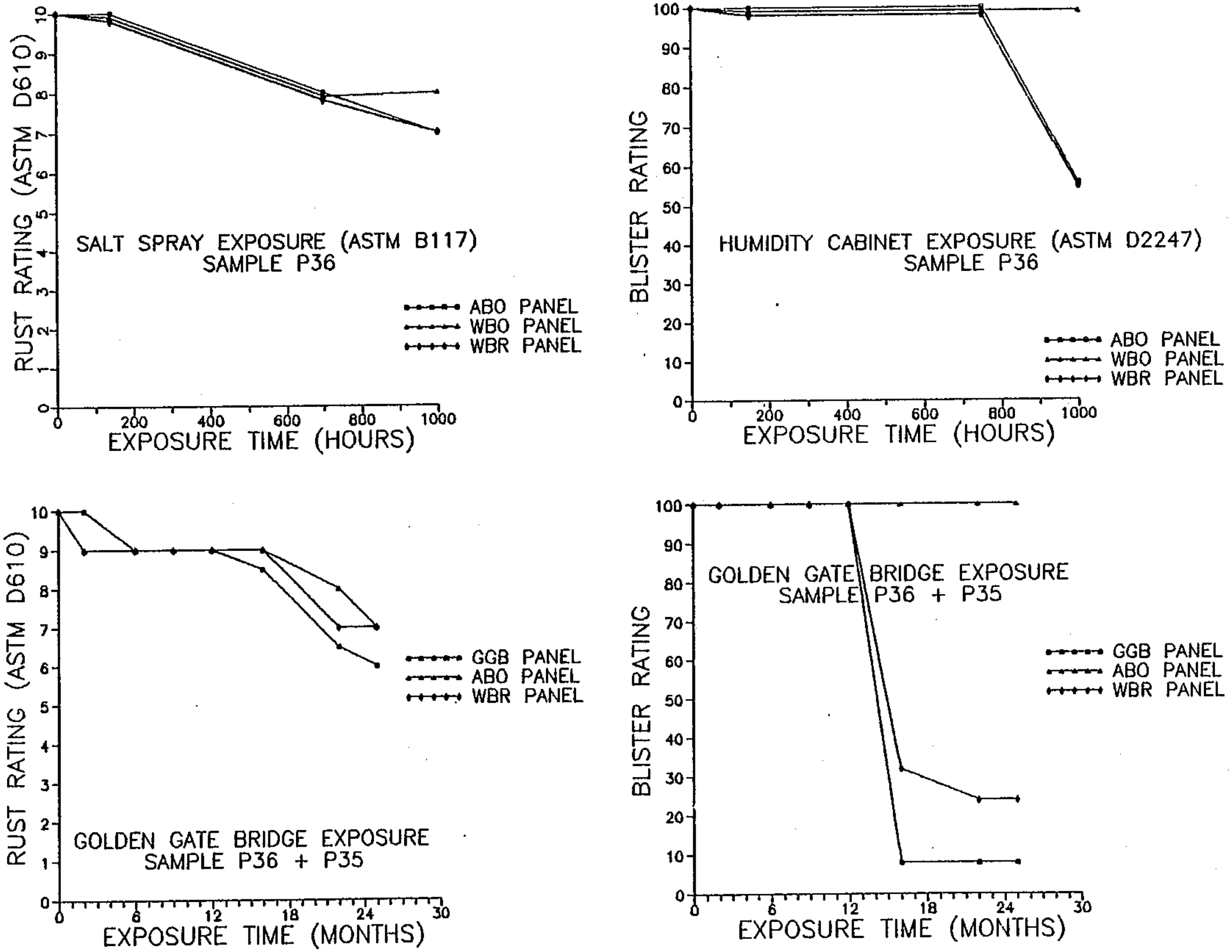
EPOXY MASTIC P35



EPOXY MASTIC P35

FIGURE XXVIII

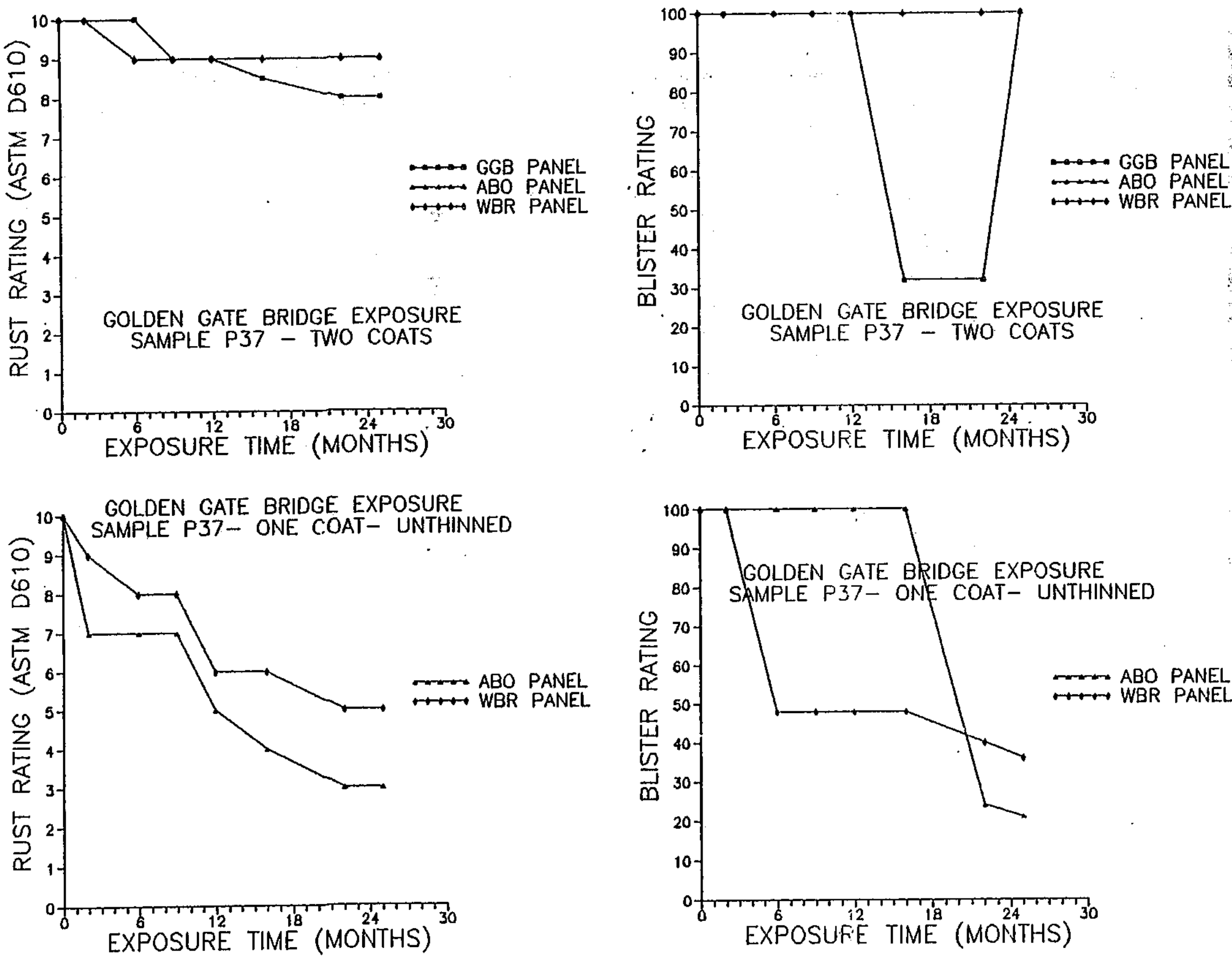
EPOXY MASTIC P35 OVER, EPOXY PRIMER P36



EPOXY MASTIC P35 OVER EPOXY PRIMER P36

FIGURE XXIX

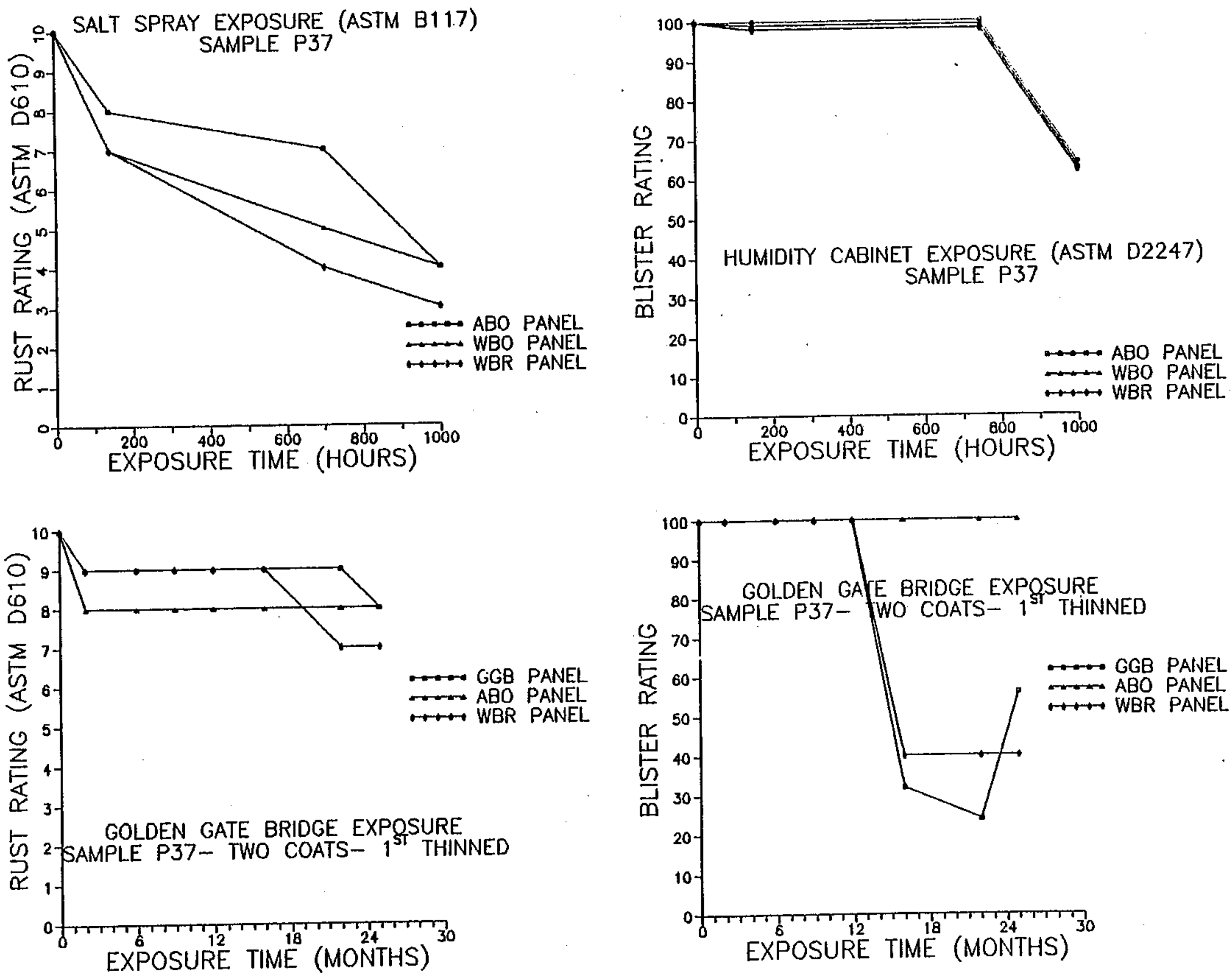
EPOXY MASTIC P37



EPOXY MASTIC P37

FIGURE XXX

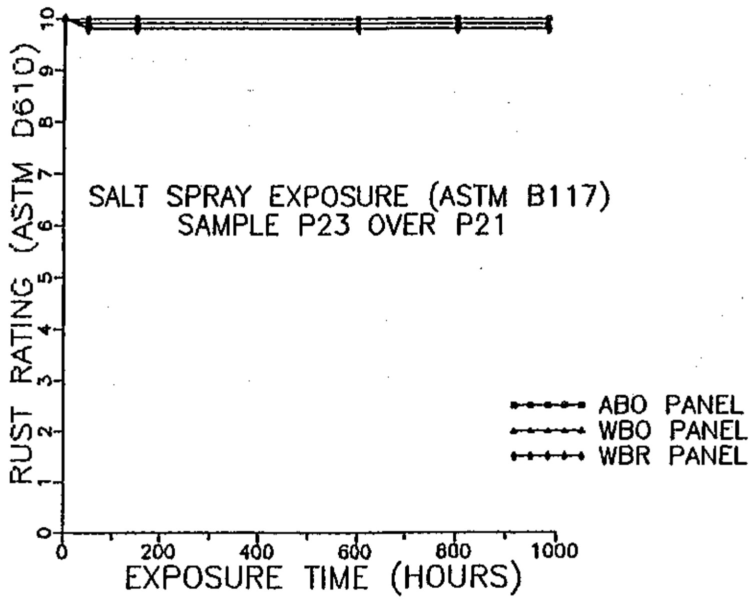
EPOXY MASTIC P37

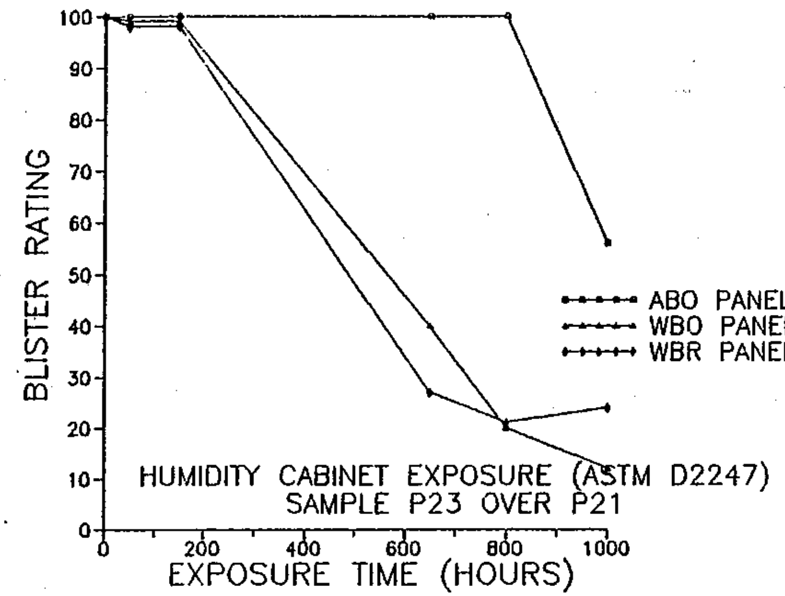


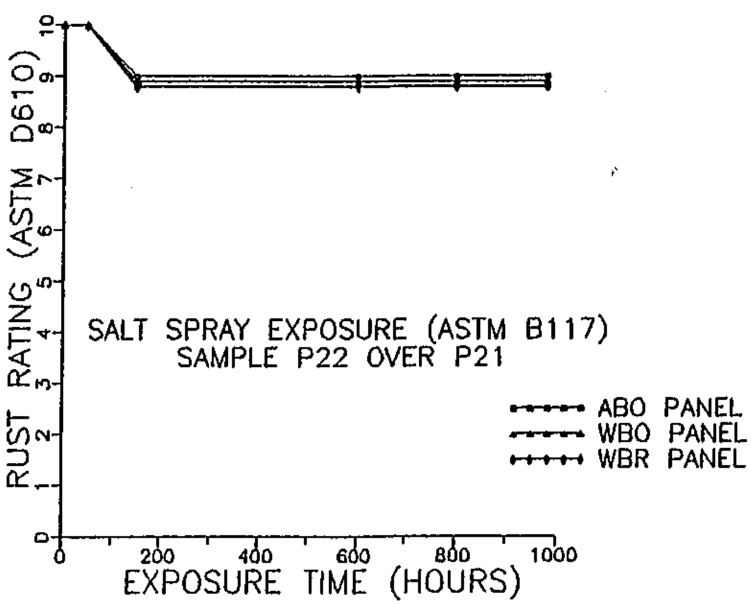
EPOXY MASTIC P37

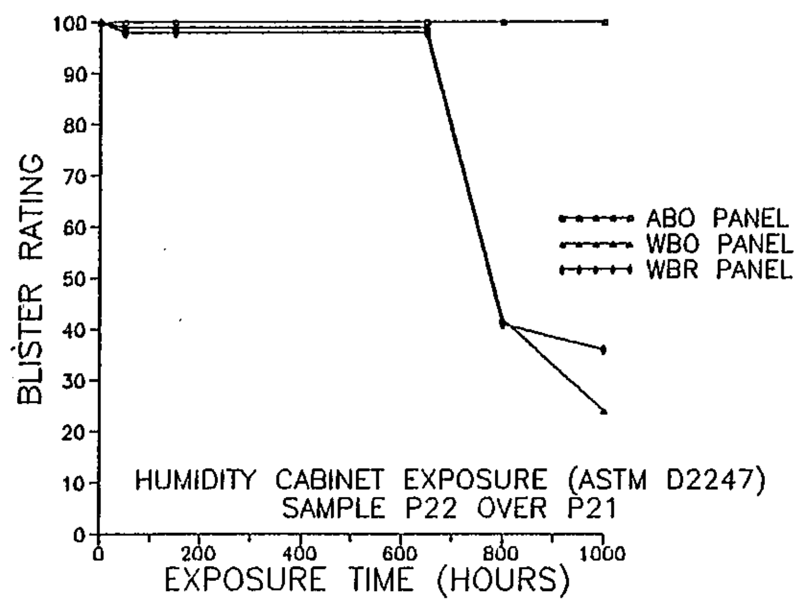
FIGURE XXXI

POLYURETHANE SYSTEM; .P23 OVER P21





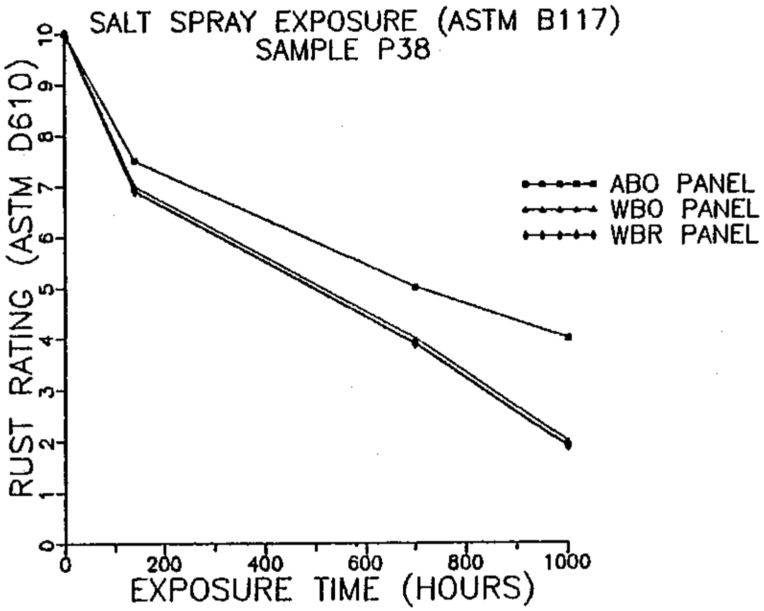




POLYURETHANE SYSTEM; P23 OVER P21

FIGURE XXXII

POLYURETHANE P38



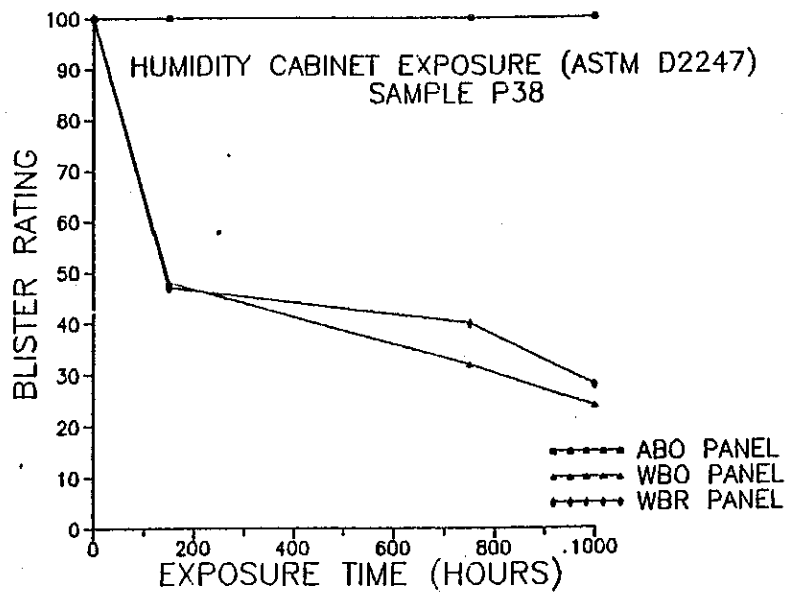
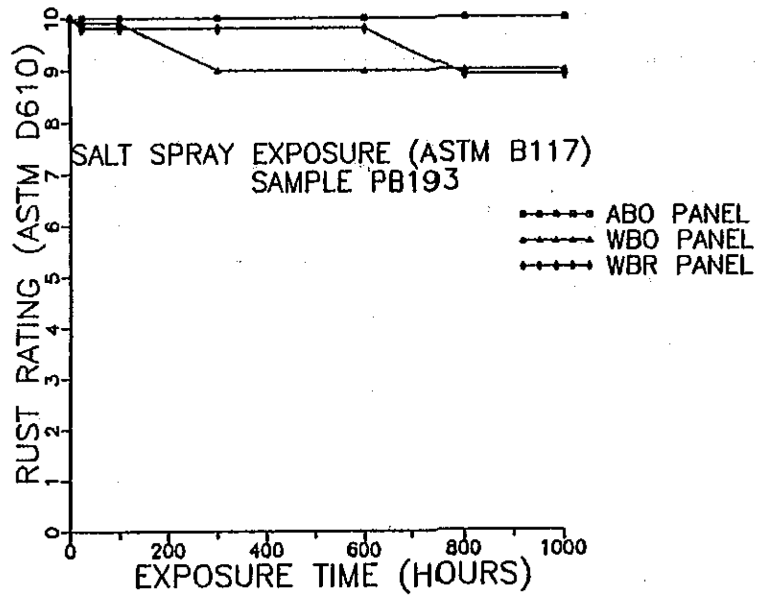
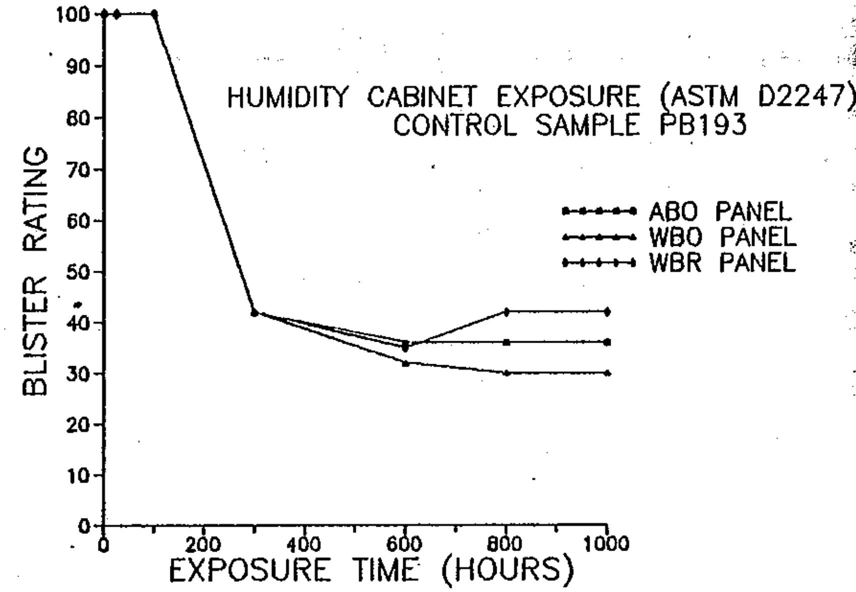


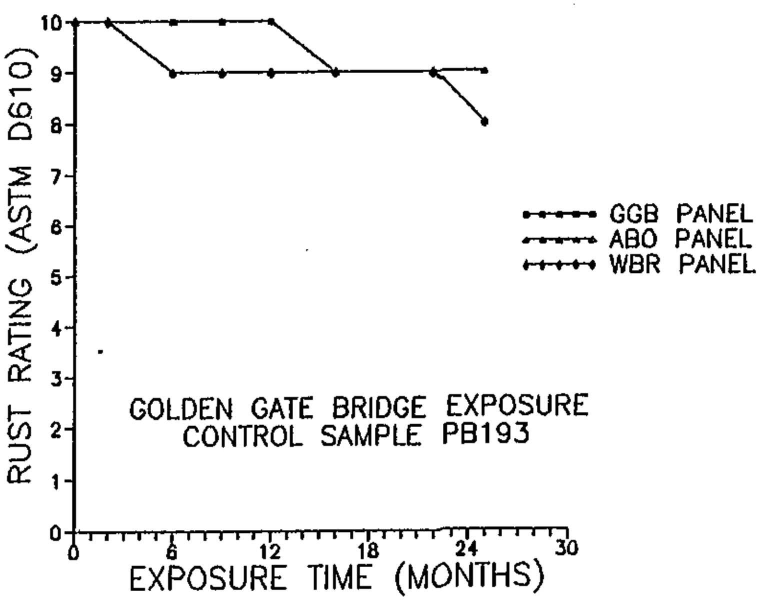
FIGURE XXXIII

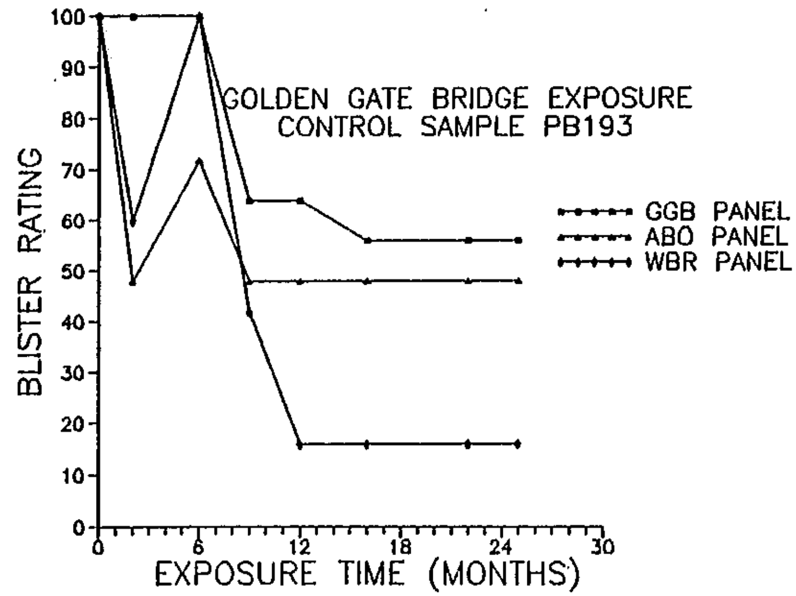
POLYURETHANE P38

PHENOLIC PRIMER PB-193





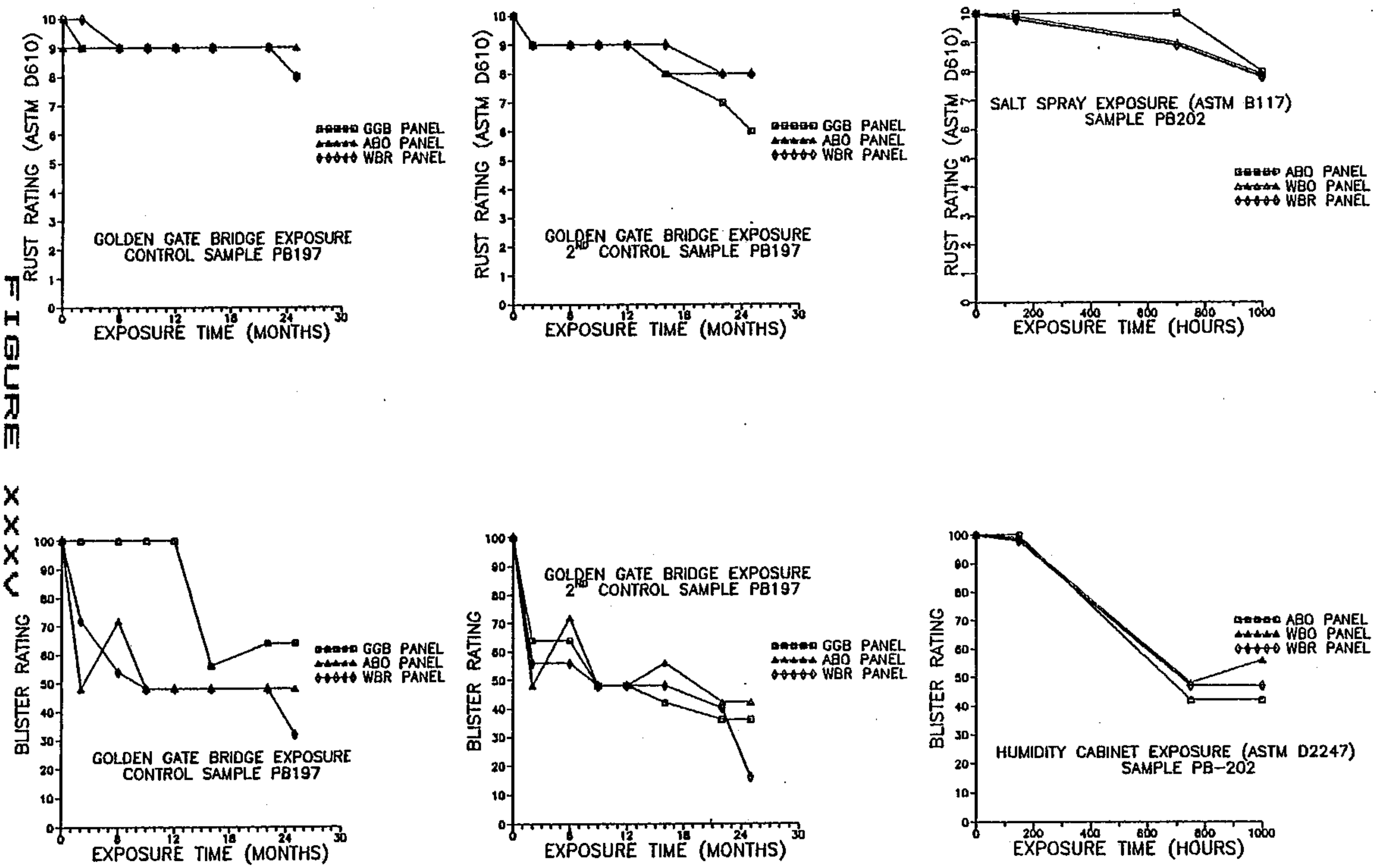




PHENOLIC PRIMER PB-193

FIGURE XXXIV

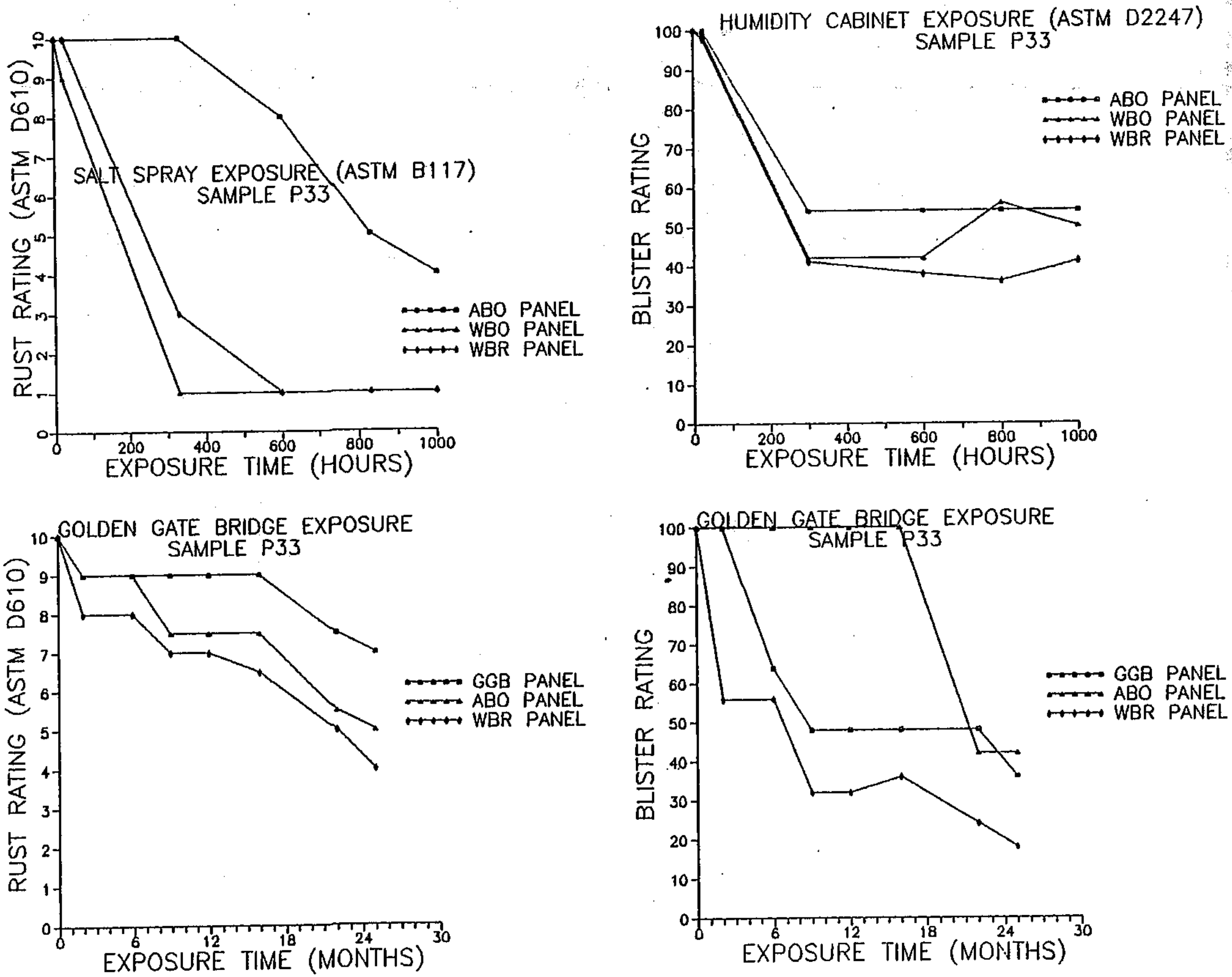
PHENOLIC PRIMERS PB-197 AND PB-202



PHENOLIC PRIMERS PB-197 AND PB-202

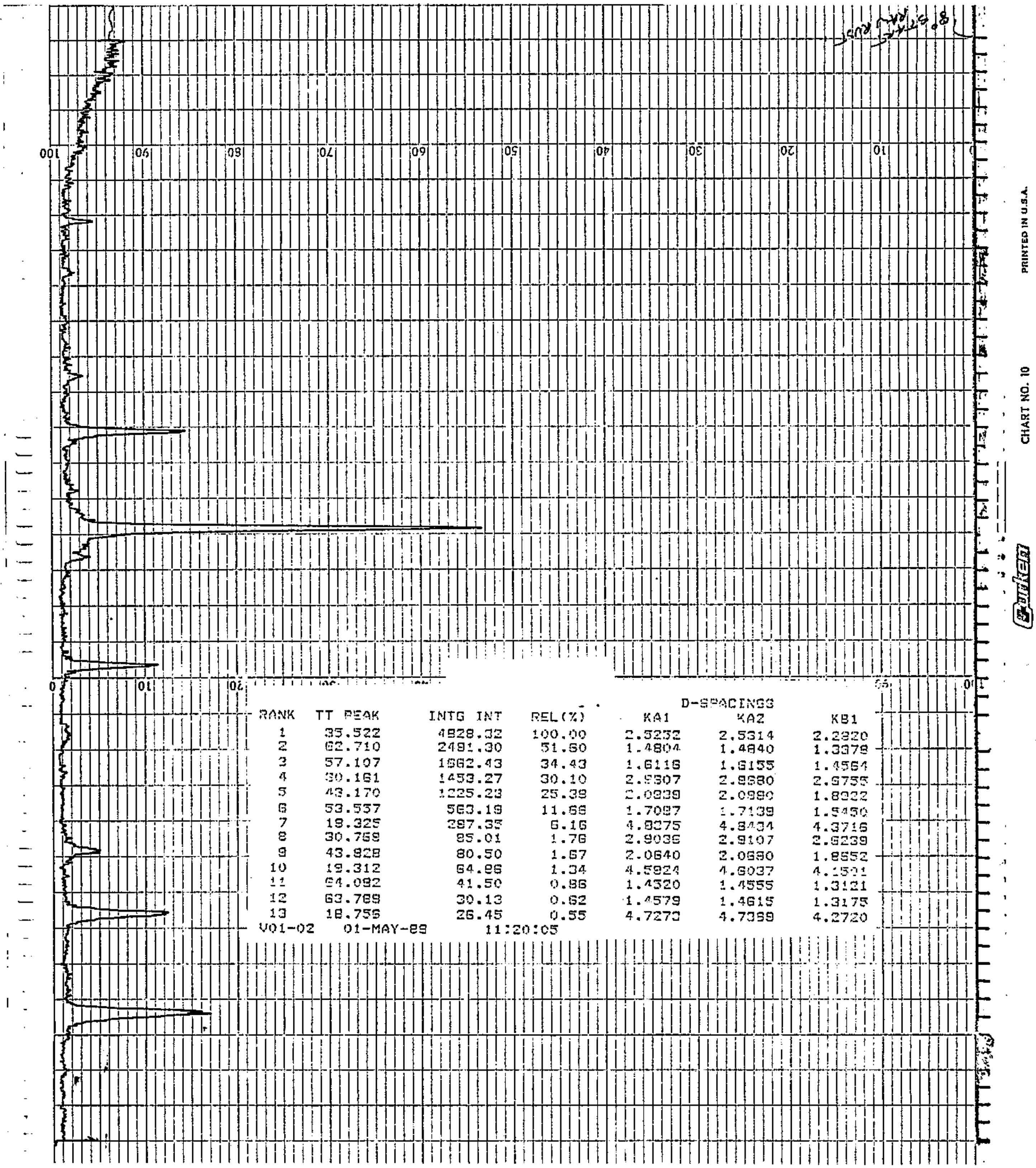
FIGURE XXXV

RED IRON OXIDE PRIMER P33



RED IRON OXIDE PRIMER P33

FIGURE XXXVI



RANK	TT PEAK	INTG INT	REL(%)	D-SPACINGS KA1	KA2	KB1
1	35.522	4828.32	100.00	2.5252	2.5314	2.2820
2	62.710	2491.30	51.60	1.4804	1.4840	1.3378
3	57.107	1662.43	34.43	1.6116	1.6155	1.4564
4	30.161	1453.27	30.10	2.9607	2.9680	2.6755
5	43.170	1225.23	25.39	2.0939	2.0989	1.8922
6	53.557	563.19	11.66	1.7097	1.7139	1.5450
7	18.365	297.35	6.16	4.8275	4.8434	4.3716
8	30.759	85.01	1.76	2.9039	2.9107	2.6239
9	43.828	80.50	1.67	2.0640	2.0690	1.8652
10	19.312	64.86	1.34	4.5924	4.6037	4.1501
11	64.092	41.50	0.86	1.4520	1.4555	1.3121
12	63.769	30.13	0.62	1.4579	1.4615	1.3175
13	18.756	26.45	0.55	4.7273	4.7389	4.2720

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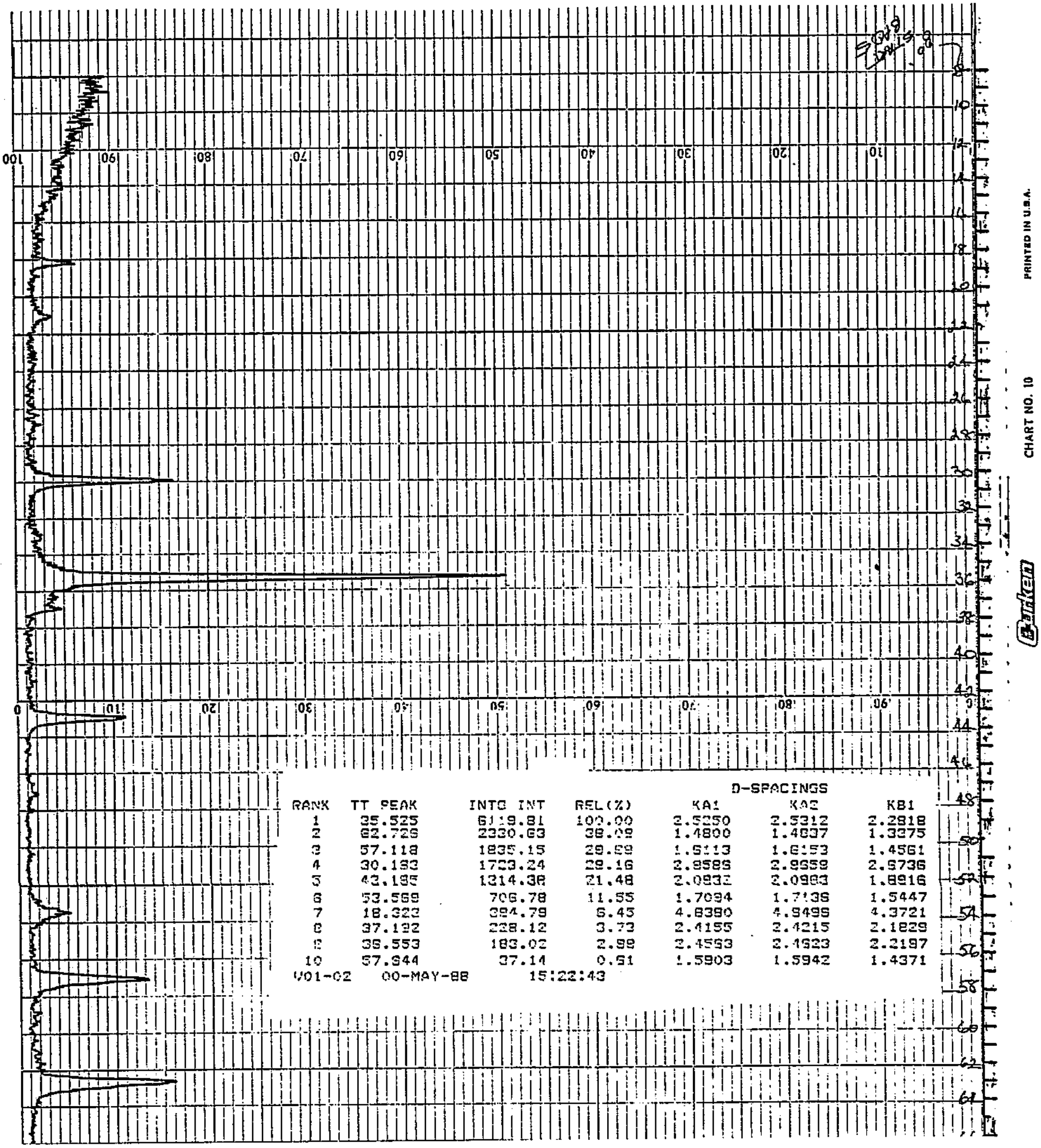
DIFFRACTION PATTERN OF UNTREATED RUST

FIGURE XXXVII



				D-SPACINGS		
RANK	TT PEAK	INTG INT	REL(%)	KA1	KA2	KB1
1	35.525	6119.81	100.00	2.5250	2.5312	2.2818
2	62.728	2330.63	38.09	1.4800	1.4837	1.3375
3	57.118	1835.15	29.99	1.6113	1.6153	1.4561
4	30.193	1723.24	28.16	2.9589	2.9559	2.6736
5	43.195	1314.38	21.48	2.0932	2.0983	1.8916
6	53.569	706.78	11.55	1.7094	1.7136	1.5447
7	18.322	394.79	6.45	4.8390	4.9499	4.3721
8	37.192	228.12	3.73	2.4155	2.4215	2.1829
9	36.553	183.02	2.99	2.4593	2.4923	2.2197
10	57.944	37.14	0.61	1.5903	1.5942	1.4371

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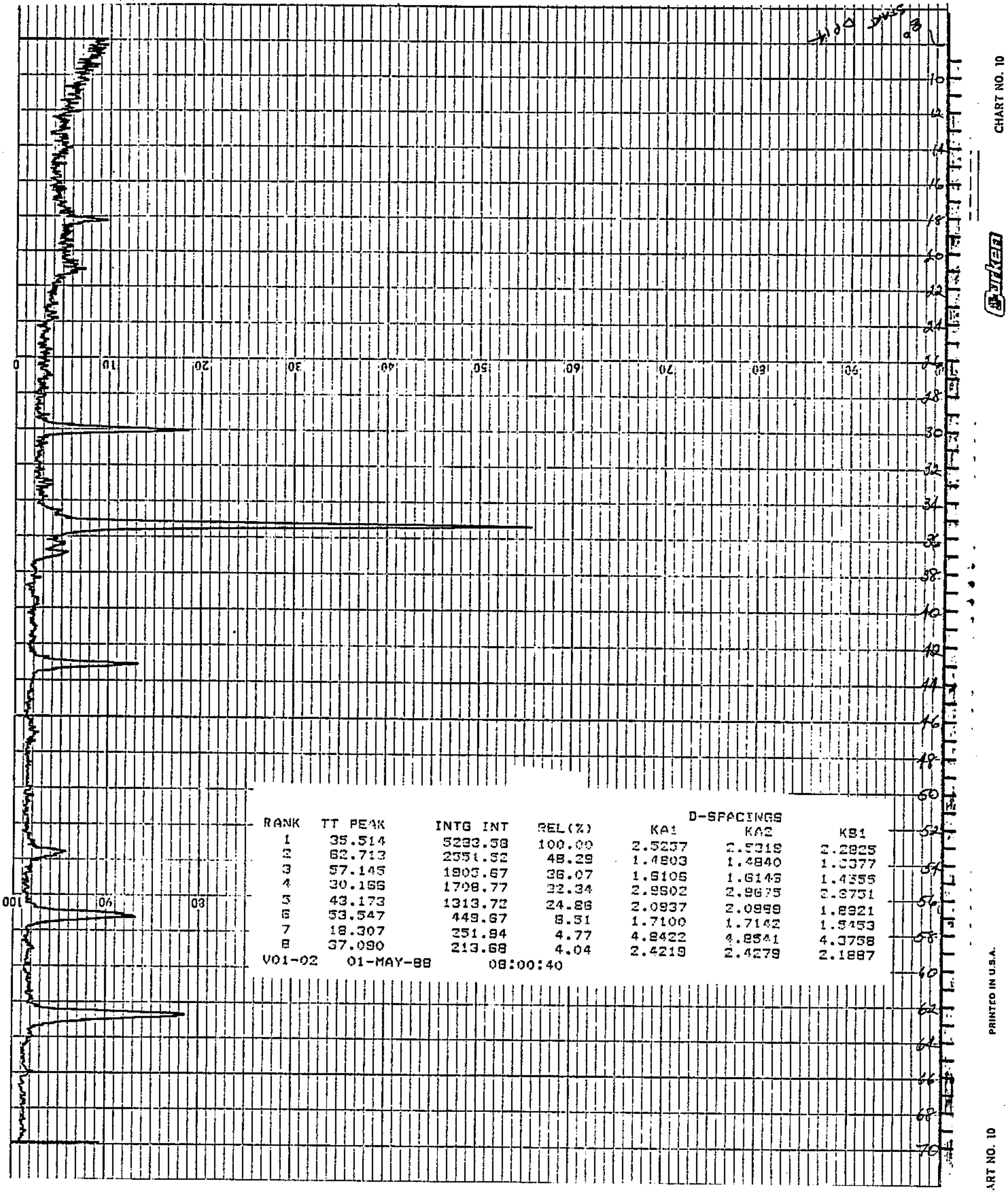
DIFFRACTION PATTERN OF RUST TREATED WITH PO5

FIGURE XXXVIII



RANK	TT PEAK	INTG INT	REL(%)	D-SPACINGS KA1	KA2	KB1
1	35.514	5283.58	100.00	2.5257	2.5318	2.2825
2	62.713	2551.52	48.29	1.4803	1.4840	1.3377
3	57.145	1905.67	36.07	1.6105	1.6145	1.4555
4	30.166	1708.77	32.34	2.9602	2.9675	2.6751
5	43.173	1313.72	24.86	2.0937	2.0999	1.8921
6	53.547	449.67	8.51	1.7100	1.7142	1.5453
7	18.307	251.84	4.77	4.8422	4.8541	4.3758
8	37.090	213.68	4.04	2.4219	2.4279	2.1887

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DIFFRACTION PATTERN OF RUST TREATED WITH P14

FIGURE XXXIX

APPENDIX B

FORMULATIONS

STATE OF CALIFORNIA

Specification

Red Primer, High Solids Phenolic Type
(Formula PB-193)

Description:

This specification covers a red, ready-mixed, air-drying, high solids, corrosion resistant, phenolic resin/tung oil primer. This coating is intended for spray application to blast-cleaned steel surfaces exposed to the air. Limited application can be made by brushing or rolling.

Composition:

PIGMENT

		Pounds/100 gallons
Magnesium Silicate	(1*)	194
Zinc Phosphate	(2*)	171
Red Iron Oxide	(3*)	194
Silica	(4*)	3

VEHICLE

Phenolic Resin/Tung Oil Varnish	(5*)	500
Aliphatic Thinner TT-T-291F, Type I		82
n-Butanol ASTM D304		3
Zirconium Drier ASTM D600, Class A	6%	4.7
Cobalt Drier ASTM D600, Class B	6%	2.4
Calcium Drier ASTM D600, Class B	5%	1.8
Anti-skinning Agent, Oxime Type		4.7

Characteristics:

Weight per gallon, pounds, ASTM D1475	11.6-11.8
Pigment by weight of paint, percent, ASTM D2371	47-49
Nonvolatile content, percent, ASTM D2369, Procedure B	79.5-81.5
Fineness of grind, Hegman, ASTM D1210	4-5
Consistency, Krebs Units, ASTM D562	78-84
Drying time at 77°F. 50% RH, 3 mil wet film, ASTM D1640	
Set to touch, hours	2.5 max.
Through dry, hours	8 max.

(1*) Magnesium Silicate, platey shape, specific gravity 2.7 +/- 0.1, *oil absorption 50 +/- 3, pH 8.8 +/- .3, Hegman fineness +6.0, 100% passing 325 mesh screen, CaO content 0.5% max., water soluble matter 1.0% max.

(2*) Essentially $Zn_3(PO_4)_2 \cdot 2H_2O$, specific gravity 3.2 +/- .1, *oil absorption 22 +/- 3, average particle size less than 10 microns, water soluble matter 0.2% maximum.

(3*) Synthetic Iron Oxide, spheroidal particle shape, Fe_2O_3 98% minimum, *oil absorption 18 +/- 2, specific gravity 5.2 +/- 0.1, 99.9% passing 325 mesh screen, water soluble matter 0.15% maximum.

(4*) Precipitated hydrophobic silica, surface area N_2 B.E.T. 120 +/- 15 m^2/g, mean particle diameter 3 microns, drying loss at 150°C 1-2%, ignition loss (2 hours at 1000°C) 5-6%, SiO_2 content 98% minimum based on substance ignited for two hours at 1000°C.

(5*) Phenolic resin/tung oil varnish shall be a 75% non-volatile solution composed of the following:

	Lbs
Union Carbide CK-2500 Resin	125
Aliphatic thinner TT-T-291F, Type I	106
n-Butanol ASTM D304	19
Tung Oil ASTM D12	250

Dissolve CK-2500 in butanol and aliphatic thinner. Add tung oil slowly while stirring.

*Oil absorption values determined according to ASTM D281.

STATE OF CALIFORNIA

Specification

Red Primer, High Solids Phenolic Type
(Formula PB-197)

Description:

This specification covers a red, ready-mixed, air-drying, high solids, corrosion resistant, phenolic resin/tung oil primer. This coating is intended for spray application to blast-cleaned steel surfaces exposed to the air. Limited application can be made by brushing or rolling.

Composition:

		Pounds/100 gallons
PIGMENT		
Magnesium Silicate	(1*)	194
Zinc Phosphate	(2*)	171
Red Iron Oxide	(3*)	194
Silica	(4*)	3
VEHICLE		
Phenolic Resin/Tung Oil Varnish	(5*)	500
Aliphatic Thinner TT-T-291F, Type I		82
n-Butanol ASTM D304		3
Zirconium Drier ASTM D600, Class A	6%	4.7
Cobalt Drier ASTM D600, Class B	6%	2.4
Calcium Drier ASTM D600, Class B	5%	1.8
Anti-skinning Agent, Oxime Type		4.7

Characteristics:

Weight per gallon, pounds, ASTM D1475	11.6-11.8
Pigment by weight of paint, percent, ASTM D2371	47-49
Nonvolatile content, percent, ASTM D2369, Procedure B	79.5-81.5
Nonvolatile content, volume percent	65.5-67.5
Fineness of grind, Hegman, ASTM D1210	4-5
Consistency, Krebs Units, ASTM D562	78-84
Drying time at 77°F. 50% RH, 3 mil wet film, ASTM D1640	
Set to touch, hours	2.5 max.
Through dry, hours	8 max.

Color to essentially match Color Chip No. PB-197 on file at the Transportation Laboratory.

(1*) Magnesium Silicate, platey shape, specific gravity 2.7 +/- 0.1, *oil absorption 50 +/- 3, pH 8.8 +/- .3, Hegman fineness +6.0, 100% passing 325 mesh screen, CaO content 0.5% max., water soluble matter 1.0% max.

(2*) Essentially $Zn_3(PO_4)_2 \cdot 2H_2O$, specific gravity 3.2 +/- .1, *oil absorption 22 +/- 3, average particle size less than 10 microns, water soluble matter 0.2% maximum.

(3*) Synthetic Red Iron Oxide, spheroidal particle shape, Fe_2O_3 98% minimum, *oil absorption 18 +/- 2, specific gravity 5.2 +/- 0.1, 99.9% passing 325 mesh screen, water soluble matter 0.15% maximum.

(4*) Precipitated hydrophobic silica, surface area N_2 B.E.T. 120 +/- 15 m^2/g, mean particle diameter 3 microns, drying loss at 150°C 1-2%, ignition loss (2 hours at 1000°C) 5-6%, SiO_2 content 98% minimum based on substance ignited for two hours at 1000°C.

(5*) Phenolic resin/tung oil varnish shall be a 75% non-volatile solution composed of the following:

	Lbs
Union Carbide CK-2500 Resin	125
Aliphatic thinner TT-T-291F, Type I	106
n-Butanol ASTM D304	19
Tung Oil ASTM D12	250

Dissolve CK-2500 in butanol and aliphatic thinner. Add tung oil slowly while stirring.

*Oil absorption values determined according to ASTM D281.

STATE OF CALIFORNIA

Specification

Red Primer, High Solids Phenolic Type
(Formula PB-201)

Description:

This specification covers a red, ready-mixed, air-drying, high solids, corrosion resistant, phenolic resin/tung oil primer. This coating is intended for spray application to blast-cleaned steel surfaces exposed to the air. Limited application can be made by brushing or rolling.

Composition:

			Pounds/100 gallons
PIGMENT			
Magnesium Silicate		(1*)	194
Zinc Phosphate		(2*)	171
Red Iron Oxide		(3*)	190
Silica		(4*)	3
VEHICLE			
Phenolic Resin/Tung Oil Varnish		(5*)	512
Aliphatic Thinner TT-T-291F, Type I			82
Xylene ASTM D846			3
Zirconium Drier ASTM D600, Class A	6%		4.9
Cobalt Drier ASTM D600, Class B	6%		2.5
Calcium Drier ASTM D600, Class B	5%		1.9
Anti-skinning Agent, Oxime Type			4.7

Characteristics:

Weight per gallon, pounds, ASTM D1475	11.6-11.8
Pigment by weight of paint, percent, ASTM D2371	47-49
Nonvolatile content, percent, ASTM D2369, Procedure B	80.0-82.5
Nonvolatile content, volume percent	66.5-68.0
Fineness of grind, Hegman, ASTM D1210	4-5
Consistency, Krebs Units, ASTM D562	76-86
Drying time at 77°F. 50% RH, 3 mil wet film, ASTM D1640	
Set to touch, hours	2.5 max.
Through dry, hours	8 max.

Color to essentially match Color Chip No. 197 on file at the Transportation Laboratory.

(1*) Magnesium Silicate, platey shape, specific gravity 2.7 +/- 0.1, *oil absorption 50 +/- 3, pH 8.8 +/- .3, Hegman fineness +6.0, 100% passing 325 mesh screen, CaO content 0.5% max., water soluble matter 1.0% max.

(2*) Essentially $Zn_3(PO_4)_2 \cdot 2H_2O$, specific gravity 3.2 +/- .1, *oil absorption 22 +/- 3, average particle size less than 10 microns, water soluble matter 0.2% maximum.

(3*) Synthetic Red Iron Oxide, spheroidal particle shape, Fe_2O_3 98% minimum, *oil absorption 18 +/- 2, specific gravity 5.2 +/- 0.1, 99.9% passing 325 mesh screen, water soluble matter 0.15% maximum.

(4*) Precipitated hydrophobic silica, surface area N_2 B.E.T. 120 +/- 15 m^2/g, mean particle diameter 3 microns, drying loss at 150°C 1-2%, ignition loss (2 hours at 1000°C) 5-6%, SiO_2 content 98% minimum based on substance ignited for two hours at 1000°C.

(5*) Phenolic resin/tung oil varnish shall be a 75% non-volatile solution composed of the following:

	Lbs
Union Carbide CK-2500 Resin	125
Aliphatic Thinner TT-T-291F, Type I	108
Xylene ASTM D846	19
Tung Oil ASTM D12	260

Dissolve CK-2500 in xylene and aliphatic thinner. Add tung oil slowly while stirring.

*Oil absorption values determined according to ASTM D281.

APPENDIX C

LISTING OF PROJECT SAMPLES

PROJECT SAMPLES

Pretreatments

The Coulter Company, Coulter MP-7

Kondor Products Corporation, Rust Stop

Nettoyeur De Metal DMR Inc., Ferbec

Rust Converters

Frank W. Dunne Co., OverRust

Hi Line Paint MFG. Co., Inc., ACT-ON

A.W.Chesterton Co., Chesterton Rust Transformer

ICI Americas Inc., Rust Conversion Coating Based on Haloflex 202 Latex

Applied Coatings Technology, INC., Corroseal

Pickering Winery Supply, PSM Rust Converter RE-84

International Fire-Protection Services, Inc., Steel Bond Coating

Surface-Tolerant Latex Paints

A-Z-Tech Finishes Industrial Coatings, A-600-72-2 Red Oxide Primer

Burke's Paint Co., Inc., Enviroprime-746

The Cortec Corporation, Cortec VCI-376 Water Shield

Burke's Paint Co., Inc., Superlife 316MD

Burke's Paint Co., Inc., Superlife 316

Burke's Paint Co., Inmc., Primecoat 767

A-Z-Tech Finishes Industrial Coatings, A-600-71-12 Red Oxide Primer

Rohm and Haas Co., Maincote HG-54 based primer # XP-54-2

Rohm and Haas Co., MV-23 bases primer # P-23-21A

American Chemical Corp., Dynabond-System 1

Rohm and Haas Co., Cementitious Primer # FL-3671-2

Rohm and Haas Co., Cementitious Primer # FL-3639-7

Nonhardening Waxy Coatings

Cortek, Inc., M-652 Anti Corrosion Compound

Witco Chemical Corporation, RP-78 High Solids Corrosion Preventive Concentrate

Witco Chemical Corporation, RP-93 High Solids Corrosion Preventive Concentrate

Epoxy Mastics

International Paint Co., Inc., Interplus 770

Porter Paint Co., Magna-Mastic Maintenance Primer

Koppers Company, Inc., Koppers Aluminum Epoxy Mastic

Devoe Prufcoat Co., Chemfast 547 Epoxy High Build Coating

Devoe Prufcoat Co., Pre-Prime Rust Penetrating Sealer

Carboline Co., Carbomastic 15

Urethane Type Coatings

Mega-Chem of California, Defender Anti-Graffitti Coating

Mobay Chemical Corporation, High Build Aluminum Tinted Urethane Primers NB #'s 370902 and 370903

Mobay Chemical Corporation, High Build Aluminum Topcoat NB # 370904

Mobay Chemical Corporation, International Orange 650/N Topcoat NB # 348049

Pure-Cote Corporation, Metallogal PUR-PR Red Oxide Moisture-Cured Polyurethane Primer/Finish

Pure-Cote Corporation, Metallogal PUR-Contact Moisture-Cured Polyurethane Intermediate Coating

Pure-Cote Corporation, Metallogal PUR-Cover Moisture-Cured Polyurethane Topcoat

Pure-Cote Corporation, Metallogal PUR-Zinc ME III Zinc Rich Moisture-Cured Polyurethane Primer/Topcoat

Carboline Company, Carbomastic D242

Solvent-Borne, Air-Drying Paints

PPG Industries, Inc., Interior/Exterior Rust Inhibitive Steel Primer 7-208 Red