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**GENERAL
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SIBILITY PROGRAM
DING THE NATIONAL
PROJECT SHIPBUILDING
OKON '71 RESEARCH
COATINGS PROGRAM
MOVEMENT PROJECT
TO SHIPBUILDING
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**Marine Coatings Performance for
Different Ship Areas. Vol. I of II**

**U.S. Department of Commerce
Maritime Administration**

**in cooperation with
Avondale Shipyards, Inc.
New Orleans, Louisiana**

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FOREWORD

This research project was performed under the National Shipbuilding Research Program. The project, as part of this program, is a cooperative cost shared effort between the Maritime Administration, Avondale Shipyards, Inc. and Offshore Power Systems, a wholly owned Westinghouse subsidiary. The overall objective of the program is improved productivity and, therefore, reduced shipbuilding costs to meet the lower Construction Differential Subsidy rate goals of the Merchant Marine Act of 1970.

The studies have been undertaken with this goal in mind, and have followed closely the project outline approved by the Society of Naval Architects and Marine Engineers' (SNAME) Ship Production Committee. The research effort for the project was assigned, by subcontract, to Offshore Power Systems.

Mr. Benjamin S. Fultz, Mr. P.J. Hawkins and Mr. Dave Sealander, of Offshore Power Systems, served as Project Manager and Senior Engineers respectively. Mr. Job Travassos, of the same company, performed all testing operations. On behalf of Avondale Shipyards, Inc., Mr. John Peart was the R & D Project Manager and Mr. Arvind Vira was the Assistant R & D Manager responsible for technical direction, editing and publication of the final report. Program definition and guidance was provided by the members of the 023-1 Surface Preparation Coatings Committee of SNAME, Mr. C.J. Starkenburg, Avondale Shipyards, Inc., Chairman.

Special thanks are given to Mr. P.R. Price, of Norfolk Shipbuilding and Dry Dock Corporation, and Mr. Walter H. Radut, of Exxon Corporation, for the supplying of numerous case histories. Also, thanks are extended to Mr. William Arbiter and Mr. Robert Manning who reviewed the draft of this report and offered valuable criticism. Also we wish to acknowledge the support of Mr. Jack Garvey and Mr. Robert Schaffran, of the Maritime Administration, and the contributions of the following corporations:

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Tnemec Company Inc., Kansas City, Missouri

EXECUTIVE SUMMARY

The objective of this project was to establish methods to reduce ship construction costs by improving the paint selection system. Toward this end, the following results were achieved:

- Establishment of a computer program of paint service histories which demonstrate that valid conclusions can be reached as to which generic paint type is best for a specified area of this ship.
- Support by laboratory testing of performance trends of the computer program analysis.
- Demonstration by laboratory testing that careful evaluation of paint suppliers is necessary. (Refer to Figure 2.1)
- Indications that careful selection of laboratory test methods and evaluation parameters, to duplicate service conditions, can serve as a screening method for candidate paint(s). (Refer to Figure 1.3)
- Establishment of a method of life cycle cost determination.
- Identification of craft interference and premature area release for painting prior to compartment completion. That is, poor paint planning and scheduling is the major cause of inordinately high ship painting costs.

If the principles identified within the body of this report are assimilated by the marine industry, millions of dollars in improved ship paint performance will be realized. Shipbuilders will benefit in two ways:

- Less dollars expended at guarantee survey time due to improved paint performance (fewer failures).
- Reduction in the probability of a catastrophic paint failure during vessel construction.

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SECTION 1

Conclusions

1. CONCLUSIONS

1.1 Project Results

The results and conclusions of this report are summarized below:

1. A computer program was established which demonstrates that valid conclusions can be reached as to which generic type of paint performs best for a given application; i.e. best antifouling, best tank coating, etc.
2. Laboratory testing supports trends of the computer program analysis.
3. Laboratory testing demonstrates that not all paint suppliers are capable of supplying all types of generic coatings and that the purchaser must know the capabilities and limitations of each source. (See Figure 2.1).
4. Careful selection of laboratory test methods and evaluation parameters, to duplicate service conditions, can serve as a screening method for candidate paint(s). (See Figure 1.3)
5. A method of determining life cycle was established.
6. Most shipyards are plagued with paint production planning problems exemplified by craft interference and premature compartment finish painting. That is, poor paint planning and scheduling is the major cause of the inordinately high cost of ship painting as compared to the cost of painting other structural steel.

1.2 Cost Savings

1.2.1 General

The selection of a coating system for new ship construction is often thought of as a "crystal ball" art form. Today there are numerous different generic paint types in the marine market place, each of which is advertised as the epitome of excellence. The shipowner is often misled into selecting exotic paint systems with high initial cost on the premise that *the higher the initial cost, the more extended the performance without maintenance. This selection method does not always hold true.* The system application may require extensive controls beyond the state-of-the-art capabilities of the prospective builder. The end result is an expensive system applied under other than ideal conditions leading to inferior performance. Likewise, the selection of a low initial cost, short life system may lead to major maintenance and upkeep costs. In neither case is the system cost effective. Therefore, the shipowner is left in a quandary. He has no reference source document to help him select

the correct paint system for the intended use or service condition.

In 1976, the 023-1 panel of the Society of Naval Architects and Marine Engineers (SNAME) identified this problem area and defined a proposed research project to investigate the possibilities of establishing an unbiased paint performance evaluation project based on actual case histories, possibly reinforced by limited laboratory testing. This report is the first step toward accomplishing that goal.

1.2.2 Use of Computer Program

An analysis of the case histories contained in Volume II of this report indicates that, with an adequate data base, intelligent, reliable selections can be made relative to the best paint system for a given type of ship and area of the ship. This capability would be extremely valuable in reducing ship procurement and maintenance costs. Shipbuilders would benefit in selections being made which are more compatible with current shipbuilding technology and reduce the potential for catastrophic paint failures during vessel construction.

Section 4 of this report contains the following number of case histories:

Underwater Bottom	282 histories
Underwater Bottom Flats	70 histories
Underwater Bottom Sides	70 histories
Boottop	217 histories
Freeboard	134 histories
Decks	54 histories
Superstructure	36 histories
Cargo Holds & Spaces	17 histories
Product Tanks	156 histories
Ballast Tanks	36 histories
TOTAL-----	1,072 histories

This represents a sizable amount of information. However, there are gaps in many of the categories. Most of the data to date has been supplied by coatings suppliers, shipyards and government agencies. With one exception, minimal data have been supplied by shipowners, the people who possess the most information and could benefit the most from the study.

A statistical analysis was performed on the available case histories. It was found that the data must contain a minimum of thirty histories per population sample and preferably one hundred case histories. This means that each

representative paint system must have a minimum of thirty histories for each possible area of use.

The data collected on the exterior freeboard area contained thirty histories of solvent based, (alkyl) inorganic zinc with polyamide topcoats and thirteen histories of a solvent based (alkyl) inorganic zinc topcoated with a chlorinated rubber. Of the thirty inorganic zinc/polyamide epoxy histories, twenty-eight were rated in the satisfactory performance bracket (0-10% failure), one in marginal bracket (15-25% failure), and one in the unsatisfactory bracket (50-100% failure). Stated differently, the inorganic/polyamide epoxy systems performed satisfactorily 93% of the time. The inorganic zinc/chlorinated rubber system only performed satisfactorily 62% of the time, or eight out of thirteen histories. No positive conclusion can be drawn from these small samples. However, trends are indicated. The wide difference indicates a need for further study.

1.2.3 laboratory Testing

Another part of this study was a limited test program to verify or support actual case histories. The exterior freeboard was selected as a representative area. This area was chosen because of the availability of the test environment and the potential of collecting adequate numbers of historical data. Solvent based (alkyl) inorganic zinc was selected as the primer because of the extensive use of this material in American Shipbuilding. Five different, well known, commonly used generic topcoats were selected. (See Table I for actual generic materials). It is interesting to note here that on the average, the (alkyl) inorganic zinc,

topcoated with a polyamide epoxy, outperformed the same inorganic zinc topcoated with chlorinated rubber. This author does not advocate that inorganic zinc topcoated with polyamides are superior to inorganic zincs topcoated with chlorinated rubber. Sufficient data is *not* available. But the similarity between actual performance and test data does exist and reinforces the indication for further study.

in addition to indicating performance trends, the laboratory tests demonstrated that *not all paint suppliers are equally capable of formulating and manufacturing all generic types of paint*. Some excel in epoxies while others excel in chlorinated rubbers (Figure 1 is very demonstrative of this point.). Properly designed test programs can screen proposed candidate paints and identify potentially poor performers. The cost of such a test program may seem expensive (approximately \$5,000.00) until it is remembered just how much it costs to replace tank coatings which have failed onboard ship (in the six figure range). It must be stressed that test programs must be properly designed and controlled. Placing steel plates painted with different materials in the steel storage yard, and then checking them at irregular intervals, is not a test program. Service environment, service conditions, type of ship, area of the ship, application methods, etc. must all be taken into consideration. Careful selection of test methods will result in the determination of the best coating systems to meet these variables. If just one test program helps to assure the paint performance in one service area of one ship, the entire cost of this project will have been repaid.

FIGURE 1.1: Grading of Weatherometer Panels

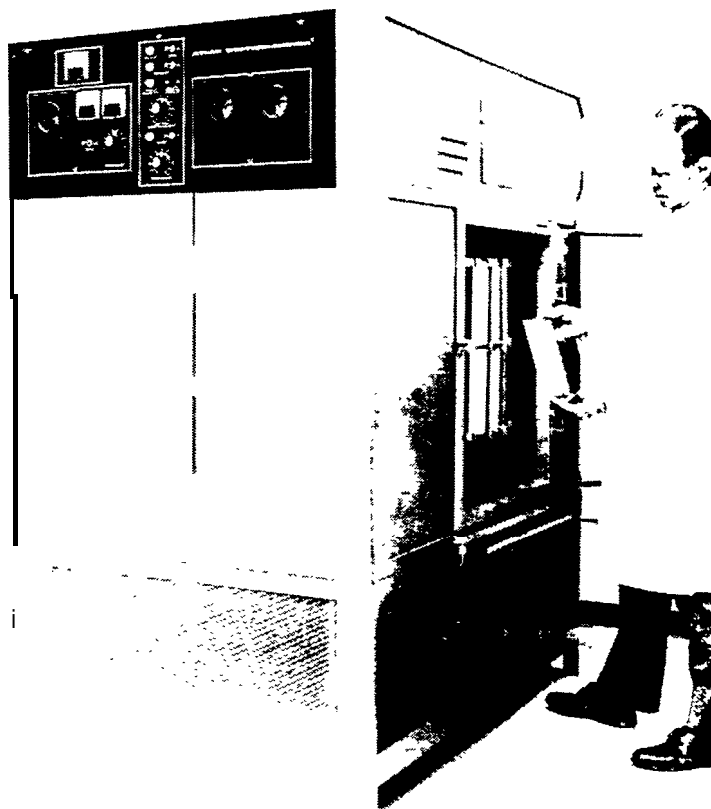


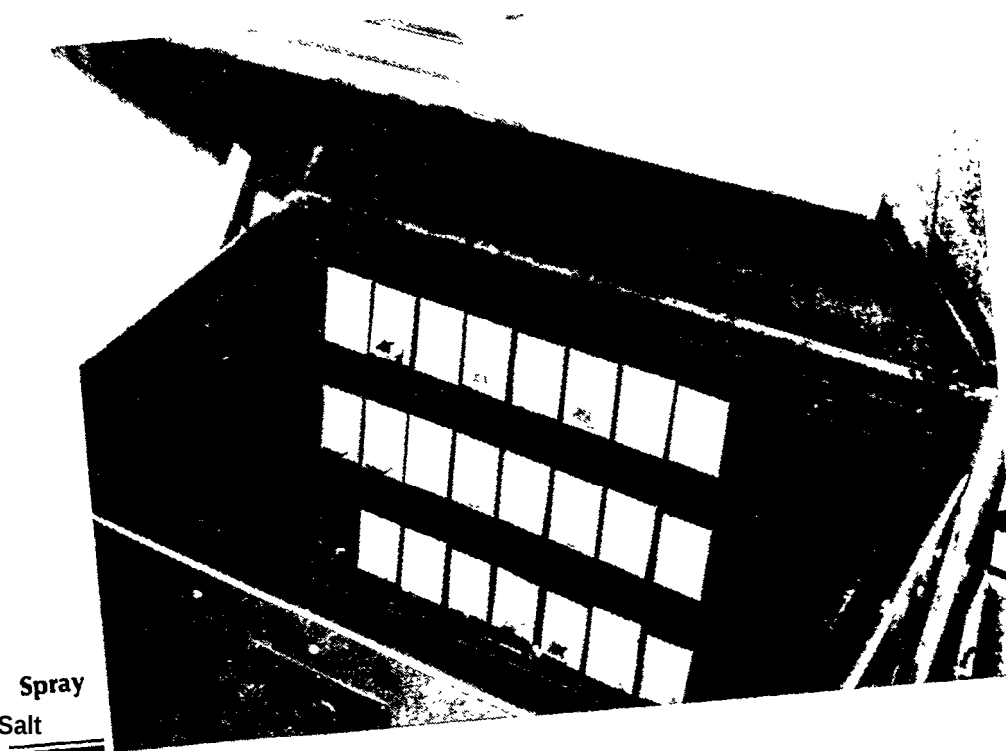
FIGURE 1.2: Grading of Salt Spray Panels

**FIGURE 1.3: Paint Test Fence
Exposure**



Spray

FIGURE 1.4: Panels in Salt



1.2.4 Life Cycle Cost

Section 2.7 of this report contains a discussion and example of how the life cycle cost of two different paint systems can be compared and evaluated. If this approach is taken in determining the selection of paint systems, many dollars can be saved by the ship owner over the duration of the useful life of the ship.

1.2.5 Paint Planning

The results OF a survey conducted during the course of study revealed that insufficient effort is expended by the shipyard on detail planning of the painting operation. The planning that is accomplished is often too easily negated by steel erection schedule pressures.

Eighteen out of nineteen responding cited craft interference and premature finish painting as major problem areas. paint planning is beyond the scope of this report, but it should be pointed out that this is a major problem. Rework is expensive. A real potential for major cost savings exists in this area.

1.3 Recommendations for Continued Research and Development

Based on the results achieved and conclusions reached by the project, the following recommendations are offered:

1. Increase the data base of performance histories.
2. Establish a computer software program for life cycle cost evaluation.
3. Establish computer software program for evaluating production parameters for various shipyard operating conditions.
4. Combine life cycle cost data and producibility rankings into a common report for specific cases.
5. Design test programs for various severe ship service areas:
 - a. Tanks, Ballast, Fuel and Cargo

- b. Underwater Bottom
- c. Boottop (one test presently in existence) (189)
- d. Decks
- e. Cargo Spaces

6. Initiate studies of planned painting operations.

1.4 Summary

This study was designed to investigate the potential of comparative analysis of paint systems in providing cost effective coating selection. Based on the trends developed in this study, and the potential for cost savings, a Phase II project should be conducted. This project should stress the enlargement of the data deck and proceed with a total cost evaluation of each major paint system and area. More data is needed to make positive conclusions as to the best generic coating systems for the different ship areas. This data collection should be an ongoing dynamic program.

For example, an owner is contemplating building a tanker of 100,000 DWT to be placed in service between New York and Alaska. He requests an analysis from the centralized data bank on which paint system or systems are best for the intended service. He then writes the generic system into his contract building specification. By this action, his chances of receiving a satisfactory coatings at a reasonable cost are materially increased.

Premature paint failures account for millions of dollars being unnecessarily expended. Every person connected with shipyard painting can relate horror stories of massive paint failures. Paint cost savings can be realized through proper material selection, based on documented service data.

The computer program developed as a result of this project offers one approach to intelligent paint selection. properly designed laboratory testing can be used to reinforce the selection. See Volume II of this report for the actual Program Printout developed as a result of this project.



FIGURE 1.5: Comparison of Conventional Alkyd System (left) and a High Performance Inorganic Zinc plus Topcoats of Epoxy and Urethane (right).

SECTION 2

Project Plan of Action and Results

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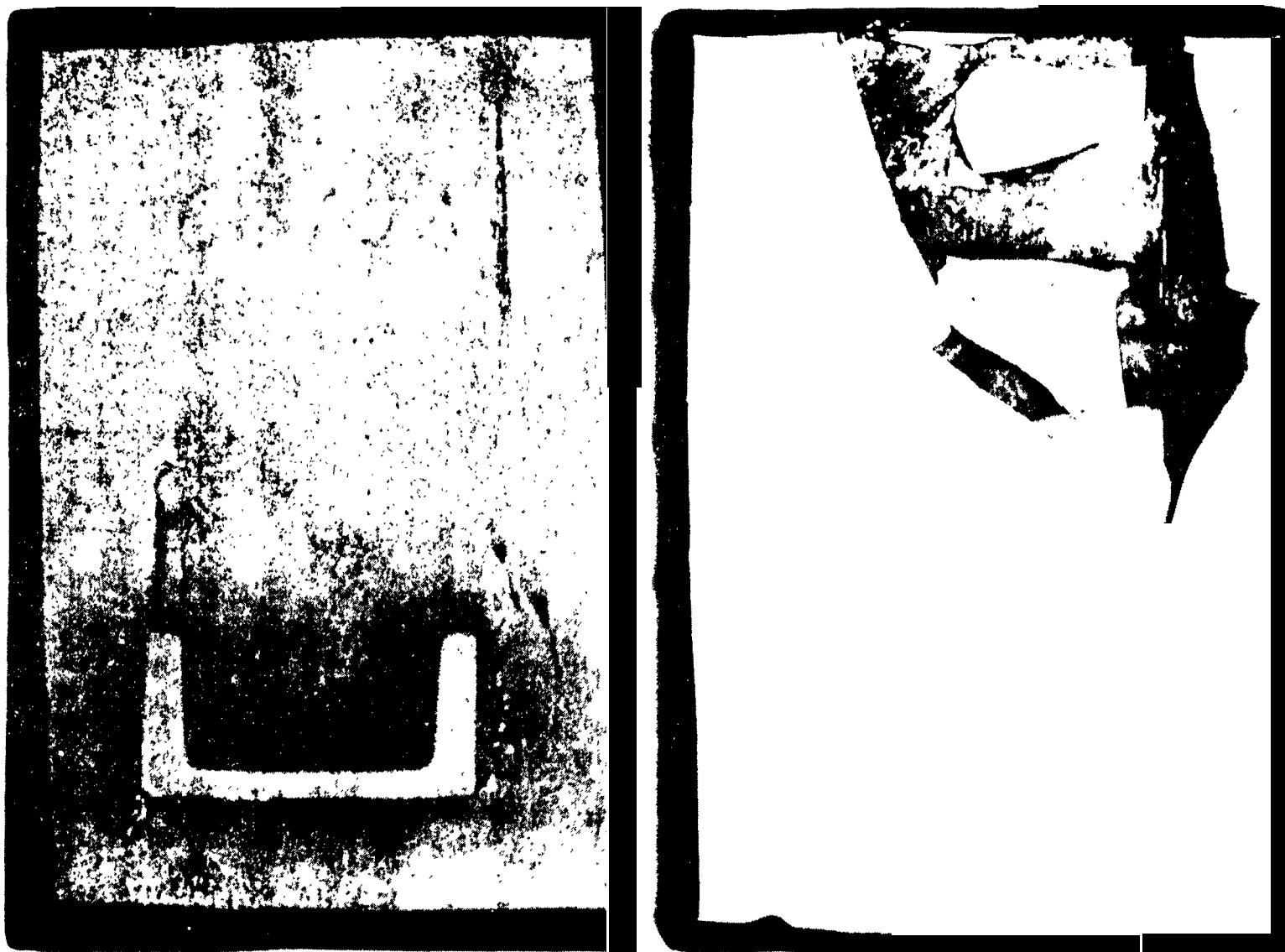


FIGURE 2.1: Two Generically Similar Paint Systems Supplied by Different Manufacturers.

2. PROJECT PLAN OF ACTION AND RESULTS

2.1 Objectives

The objective of this project is the establishment of an analytical program of scientific paint selection based on projected use as defined by the type of ship, trade route and operating environment.

2.1.1 Phase I— phase I was designed primarily to test the ability to establish an analytical program of paint selection based on developed evaluation criteria. This objective was achieved. Sections 3 and 4 of this report contain the actual program.

2.1.2 Phase II — Since Phase I was a success, a Phase II program is warranted in which the data base is enlarged and additional computer software programs are developed. Positive conclusions as to which paint is most suitable for a given service condition can be made with a sufficiently large data base.

2.2 General Approach

As originally envisioned, the project was broken into six tasks. The first three tasks concerned the establishment of evaluation criteria. The remaining

tasks concerned the compilation of data and the analysis of results. The paragraphs which follow discuss the sequence of events leading to, and the rationale behind, the selection of evaluation criteria and final systems analysis.

2.3 Evaluation Criteria Determination

2.3.1 Determination of Paints/Coatings Criteria. Constraints Imposed by Shipbuilding Practices and Environments.

Immediately after the contract award, a questionnaire was formulated and sent out to all major United States and selected foreign shipyards. Annex A contains the sample letter and questionnaire.

Nineteen companies responded to the request for information. All major shipyards were represented and numerous smaller yards responded. All geographical areas were included. Figure 2.1 contains a list of responses by geographic area.

North East Atlantic	— Three
Mid Atlantic	— Two
Gulf	— Five
North West Pacific	— Three
South West Pacific	— Two
Inland Waterways	— Three
Great Lakes	— One

TABLE 1: Number of Shipyard Questionnaire Responses by Geographical Area

Most of those shipyards responding purchase steel plates and structural shapes unprimed with intact mill scale. Approximately the same number of these do prefabrication priming operations as well as post fabricating cleaning and priming. The primary consideration for prefabrication priming are steel corrosion protection and providing a cleaner working environment for craft personnel. Only six cited contract requirements as a reason.

When queried as to the removal of initially applied primer (pre or postfabrication) only one completely removed the primer prior to final painting.

Thirteen yards perform initial surface preparation using a combination of manual and/or automatic abrasive blasting techniques. only one used automatic power tool cleaning as the means of initial surface preparation.

Touch up surface preparation is generally accomplished via either manual abrasive blasting or power tool cleaning.

The majority of yards do not attempt automatic nor semiautomatic welding through the fabrication primer. Listed below is a recapitulation of the "weld thru" responses:

Weld Process	Number Using *	Number Not Using
Maunal Stick	13	6
SAW	5	14
SMAw	6	13
GMAW-Solid Wire	6	13
GMAW-Cored Wire	5	14
FAB	2	17

* Most Cited reduced welding speeds.

TABLE 11: listing of Weld-Thru Primer Processes

The three major generic types of primer used are inorganic zinc, epoxy, and wash primer. Depending upon the type of primer used, the performance life during construction ranged from three months to twenty-four months with most listing three to twelve months.

Tables III — VI contain a listing of categories of

constraints which could possibly impose difficulty on paints and coatings operations and a response from each shipyard as to whether or not the problem is applicable to their particular manufacturing operation. A “yes” response indicates an existing problem, and a “no” response indicates the lack of a problem area.

Specific Problem	Number Yes	Number No
(1) High Humidity	15	4
(2) Low Humidity	1	18
(3) High Temperature	7	12
(4) Low Temperature	14	5
(5) Sudden Rain Showers	15	4
(6) Long Periods of Rainy Weather	8	11
(7) Snow and Ice	2	17
TABLE III: Weather Constraints		
(1) interference from Other Crafts	18	1
(2) Lack of Required Tools	1	18
(3) Lack of Skilled Craftsmen	9	10
(4) Lack of Accessibility to Job	9	10
(5) Poor Ventilation	12	7
(6) Poor Lighting	8	11
TABLE IV: Production Constraints		
(1) Interference from Other Crafts	18	1
(2) No Planned Paint/Coating Activities	4	15
(3) Work released for finish paint prior to compartment completion	16	3
(4) Written process instruction not available to paint craft personnel	3	16

TABLE V: Planning Constraints

Specific Problem	Number Yes	Number No
(1) Short Pot Life	12	7
(2) Slow Cure/Dry	12	7
(3) Unpleasant Odor	7	12
(4) Low Flashpoint	7	12
(5) Minimum Recoat Time Too Long	12	7
(6) Maximum Recoat Time Too Short	5	14
(7) Lack of Application Instructions	2	17
(8) application Method Too Complicated	2	17
(9) Surface Prep Cannot Be Accomplished	4	15

TABLE VI: Paints/Coatings Material Constraints

The conclusions which can be drawn from the results of the shipbuilder questionnaire survey are as follows:

1. Most shipyards are very similar in their approach to initial cleaning and priming. The major difference is prefab versus post fab priming.
2. Most shipyards use similar primers.
3. Most shipyards do not attempt extensive welding through primed steel.
4. The major weather constraints are similar in most shipyards, the exception being snow and ice in northern yards. Most are confronted with high humidity, sudden rain showers, and low winter temperatures. Only the extent (length of time) of cold conditions vary.
5. Practically all shipyards are plagued with interference to paint craft personnel from other craft personnel. Eighteen of those responding cited this problem area. Management should take note of this problem and improve the detailed planning and scheduling of paint operations.
6. The major material problems center around two component materials. Interestingly, short pot life and slow cure are cited as major problems. These two properties are interrelated. Shorter pot life means faster cure and vice-versa. This is also directly related to the cold weather problem since most component materials do not cure below 50°F, although some marine coating suppliers are marketing low temperature epoxy systems.

The above points can be factored into an evaluation program which establishes production parameters as a decisive factor in

the final system selection. This is accomplished by establishing a minimum production performance parameter limit for each evaluation point; e.g., relative humidity, weather sensitivity, etc. A performance parameter failure would then be grounds for rejection of a paint system selection. For example, two candidate paint materials are being investigated for use on a new contract. Both have relatively the same in-service performance characteristics.

Systems A requires a water base, self cure inorganic zinc primer and System B requires an alkyl inorganic zinc primer. The contractor's yard is located on the Gulf of Mexico. The material suppliers establish that the waterbased material cannot be applied at a relative humidity above 70%. The alkyl inorganic zinc is established as being humidity insensitive to percents above 95. Studies at the contractor's facility show that on 90% of the available work days, the relative humidity ranges above 80%. The extended number of days with high relative humidities then predicts a parameter failure on the waterbased zincs. This same procedure holds true for any weather sensitive production parameter. Each paint system must be evaluated on the basis of these parameters by the individual applicator.

Production evaluation parameters have not been built into the present program because of the variances among shipyards. However, the performance evaluation sheet does have an entry for shipbuilders. This information has been collected and could possibly be used to equate generic paint system performance to geographical location of the ship construction yard. Again, an increased data deck is needed.

2.3.2 Determination of Coating System Criteria Dictated by Operating Service Conditions.

The original plan called for a polling of shipowners and operators to determine criteria. Out of ninety-five polled, only one provided substantial information. With the lack of available input from owner/operators, a literature search was accomplished to establish evaluation parameters. As a result of this survey, the following criteria were included in the service history survey form:

- . Type of Ship
- . Age of Ship
- Age of Paint System
- . Trade Route

In addition, each ship is divided into eight performance areas:

1. Underwater bottom
2. Boottop
3. Freeboard
4. Decks
5. Superstructure
6. Cargo Holds and Spaces
7. Product Tanks
8. Ballast Tanks

This information is included in Sections 3 and 4 of this report.

2.3.3 Survey of the Major Coating Manufacturers for Coating Criteria.

Annex B contains a recapitulation of the "Marine Coatings Suppliers Questionnaire." The paint system selection criteria, as listed by coating suppliers in order of priority, are as follows:

1. *Performance* — The applied generic coating system accomplishes the intended result for which it is applied.
2. *cost* — Cost per square foot of applied coating system calculated over the life cycle of the vessel.
3. *Application Conditions & Restrictions* — Ability to apply the specified coating under the conditions imposed at the time of application.
4. *Paint Formula Design*
5. *Qualified Applicators*
6. *Maintainability of Applied System*
7. *Qualified Inspectors*
8. *Safety*
9. *Availability of Materials Both Initially and During Overhaul*
10. *Financial Soundness of Vendor*

In most cases these criteria closely correlate criteria established by shipbuilders and literature sources. As a result, performance was selected as the dominant parameter for case history evaluation.

The terms percent corrosion, percent failure and percent fouling are used. The most meaningful term is percent failure. This is a direct measure of the systems ability to perform. By definition, failure is a lack of performance for the intended purpose, whether it be fouling and/or corrosion of the substrate.

2.4 Compilation of Service Histories

As a result of the surveys, questionnaire responses and literature reviews, the "Ships/Paints Coatings Performance-Service Histories Questionnaire" was formulated (See Annex C). This task was originally scheduled to be accomplished during the last stages of the project. However, due to a need to standardize historical data, the form was created during the early stages. This form incorporates the following information:

1. Ship types representative of the different service conditions
2. Types of coatings used
3. Inspection criteria and frequency
4. Means of documentation

Section 4 of this report contains the compilation of historical performance data.

2.5 Analysis of Compiled Service Histories

2.5.1 Background Information

The major effort expended in this project was toward the systematic collection of historical paint performance data. Section 4 of this report is the result of that effort. The numbers of histories are impressive but incomplete to perform a true comparative performance analysis. However, some trends can be noted. With an enlarged data deck for reference, more definitive conclusions can be made.

The inspection data was processed into an analysis deck which was then used to provide detailed information on specific service histories. Each service history has a separate, distinct control number. This number does not appear in the final report. It is printed on the right hand tear-off margin. The code number is unique in that it identifies the source of data and a numerical sequence. Close scrutinization between this code number and the rating of a given service history can result in the rejection of some supplied data.

For example, a biased source may desire to make a given generic material appear to possess better than true, actual performance characteristics. Close examination of the service history, by a knowledgeable individual, can normally detect favoritism; e.g., all extremely good reports with no failures. The philosophy used throughout this study was "When in doubt, do not use the information". With a larger data base, this judgment can be made statistically by determination of a variance from the true mean.

The compiled data is presented in tabular form, and the columns of the report from left to right are explained as follows:

Type of Ship — Self Explanatory. Even though exact ship sizes are not given, a general idea can be gained. Small craft and barges are identified.

Trade Route — Self explanatory.

Area/System — The first print gives a description as to which performance area of the ship is being evaluated. Each ship is divided into eight different areas. Listed under the area is the generic paint system used to include number of coats.

Surface Preparation — The codes used are the Steel Structures Painting Council Surface preparation Standards or a description of the process.

System Age — This is the actual age of the system being rated. It could be the same as the ship's age if the evaluation was completed during the initial survey period, or it could be the time since the last overhaul if the system was applied at that time. Old, intact material could be a part of the system if retained after the completion of the overhaul surface preparation.

Film Thickness — Actual average film thickness of each coat of paint.

Ship's Age — Age of the ship counted from initial delivery of the ship from the shipyard to the owner.

Performance Evaluation — This section is broken into five parts for underwater bottom evaluations and three parts for all others.

% Corrosion — This is the actual percent of corrosion (rust) of the surface expressed as a %. The rating takes into consideration the entire surface area and does not attempt to define extreme localized failures.

% Coatings Failure — By definition this is a measure of the system's inability to perform its intended purpose. This could be a fouling failure, corrosion failure, cosmetic failure or a system failure; i.e., a delamination between coats of paint. This number is always the larger of the numbers which express % fouling, corrosion or other failure.

% Fouling — Measure of the amount of surface area fouled. For example, a ship may have 100% fouling between the waterline and six feet below the waterline. The remainder of the hull may be free of all fouling. The system would not be considered as 100% fouled but at some percent which takes into consideration the entire hull surface area. Since this particular phenomenon is common to underwater bottoms, an attempt was made to rectify the situation by dividing the underwater bottom into two additional subareas, namely underwater bottom-flats and underwater bottom-sides.

Type Fouling — Self explanatory. This is important because some types of fouling have more of an influence over ship performance to include increased fuel consumption. Shell has a maximum influence; slime has minimum influence.

2.5.2 Analytical Objective

The objective of this analysis is to determine if a difference exists between generic paint systems from performance evaluations and/or laboratory tests. To make a statistical test for a difference, it is important to remember that there are two types of errors possible. The first is to say that a difference exists when it does not, the so-called "Alpha" risk or "error of the first kind". It would probably soon be found out from trials or other experimentation that a mistake had been made and no great loss experienced. On the other hand if the conclusion was that no difference in performance between generic paint systems exists when in fact it does, the "error of the second kind", further experimentation would not be accomplished and the possibly less efficient, or less profitable system, selected. This could result in a great loss compared to the relatively small amount of money necessary to check further.

If an infinite number of performance evaluations are accomplished on each paint system for each area of the ship, the group of

evaluations would constitute a distribution, whose mean would be the population or true mean, and whose "standard deviation" represents the dispersion of the observations around population mean.

Since it is impossible to make an infinite number of observations on each paint system for each ship area, the question then becomes what is the minimum number of samples which must be taken to achieve a reasonable confidence in any conclusions drawn. In other words, the key to the limitations of both kinds of errors in analyses of this kind is the number of samples or performance evaluations taken to determine probable performance. Using statistical formula and methods, it has been determined that the minimum number of samples required to support an assumption of the normal distribution is thirty. The preferred number is one hundred. Using this logic, the analysis in section 2.5.2 was accomplished.

2.5.3 Comparative Analysis

To test for differences, the underwater bottom area to include flats and sides was used as a model. In general, underwater bottom systems are replaced at one, two, or three year time intervals but rarely extend beyond two years. Therefore, the age of the system drops out as a variable. It is interesting to note at this point, that a similar number of data points fell within each failure grouping regardless of the exact age of underwater systems as long as the maximum interval was held at three years. The variable, trade route, was not considered because the

sampling was taken on a world wide basis. Therefore, performance is being compared on a world wide basis.

Based on the available histories, the following types of anti fouling finish coats were considered for evaluation and comparison. please note that this is not a comparison of all the available types of antifouling but only those which meet the minimum requirement of at least thirty histories.

1. Antifouling, Chlorinated Rubber, Copper
2. Antifouling, Epoxy, Copper
3. Antifouling, Vinyl, Copper
4. Antifouling, Other
5. Antifouling, Copper/Organometallic
6. Antifouling, Resin Soap, Copper

The "Ships Paints Performance - Service Histories Questionnaire" includes ten different percent rating possibilities. For the purpose of this analysis, these ten ratings were combined into three groupings. This grouping helps to factor out possible variations in ratings by different individuals. The three groupings are:

- 0-10% — Satisfactory
- 11-25% — Marginal
- 26-100% — Unsatisfactory

Unsatisfactory systems should be replaced at the earliest convenience due to increased fuel consumption leading to poor economics of operation. Of the systems evaluated, the following results were obtained.

System	No. of Histories	% Histories Satisfactory Range	% Histories Marginal Range	% Histories Unsatisfactory Range
1. Antifouling, Epoxy Copper	45	62%	16%	22%
2. Antifouling, Copper, Organometallic	75	60%	16%	24%
3. Antifouling, Vinyl, Copper (Mil Spec)	30	53%	20%	27%
4. Antifouling, Other	39	46%	26%	28%
5. Antifouling, Rosin soap, Copper	131	45%	17%	38%
6. Antifouling, Chlorinated Rubber, Copper	27	38%	19%	38%

TABLE VII: Underwater Bottom System Rankings

This analysis indicates that on a world wide basis, Copper, Epoxy Antifouling paint systems are the best and Chlorinated Rubbers are the worst. If sufficient histories were available, trade route and/or type of ship could be

considered as variables. The computer program, written as a part of this study, has the capability of sorting data by trade route and type of ship.

2.6 Laboratory Tests

2.6.1 Discussion

As stated in Section 1, Conclusions, a limited test program was initiated to verify or support actual case histories. The exterior freeboard was selected as a representative area. This area was chosen because of the availability of the test environment and the possible potential of collecting adequate numbers of historical data. There appears to be a correlation in trends between the case history data and the laboratory test results.

2.6.2 Systems Tested

Table VIII includes the Paint Systems tested. In general, ten suppliers submitted wet samples of paint which were product matches for the generic description of the requested systems. Five primary systems were compared with some alternates being tested. The primer in all but two cases was a solvent based, (alkyl) inorganic zinc. The topcoats were polyamide epoxy intermediate with and without topcoats of either aliphatic polyurethane, silicone alkyd, or alkyd. The other two systems had intermediate and topcoats of chlorinated rubber or vinyl. The film thicknesses listed are average film thickness measurements.

2.6.3 Test Panel Preparation

Three types of panels were used for testing:
6" x 18" x 1/4" hot rolled plate for exterior test rack,
3" x 9" cold rolled for Weatherometer, and
4" x 6" x M" hot rolled "KTA" panels for salt spray.

All panels were abrasive blasted to near white, SSPC-SP10. The materials were applied by a senior laboratory technician skilled in paint application but not more knowledgeable of one material than the other. Material application sheets supplied by each vendor were used to determine thinning, application and overcoat time requirements. No special procedures nor special considerations were granted.

2.6.4 Test Environment

The prepared and painted test panels were exposed to the following test environments:

PANEL	TEST ENVIRONMENT
4" x 6" x 1/4" Steel KTA	Salt Spray-ASTM B-117 modified to use synthetic sea water as opposed to 5% NACL Solution 2,000 Hours
3" x 9" Steel 6" x 18" x M" Steel	Weatherometer-I 1000 Hours Test fence-45 degrees South Six Months and continuing

2.6.5 Test Results

Tables IX and X contain the results of these tests. Figures 2.1 thru 2.12 contain photographs of the actual panels. The system numbers listed in Table VIII are noted on a layout diagram which precedes each photograph. "The reader can match the alpha-numeric code on the layout to the corresponding position on the photograph and then look to the corresponding position on the photograph and then look back to TABLE VIII to find the exact system information.

As can be seen from the test data, differences in chalking and percent change in gloss are easily detected. These results generally agree with other published test results. Epoxies chalk more than chlorinated rubbers and chlorinated rubbers chalk more than aliphatic polyurethane.

It can also be seen that in the one case tested, aliphatic polyurethane (A-6, B-3, E-5, H-4, F-2, K-4, L-3, J-2, 1-6) outperform aromatic polyurethane (F-3). (See Table X and Figure 2.9).

The panels subjected to the salt spray test are not as easily ranked by generic type. On the average, epoxies outperform chlorinated rubber but there are exceptions in each case. For example, epoxy system A-3 outperformed chlorinated rubber system H-6, but chlorinated rubber system A-7 outperformed epoxy system K-2. (See Figures 2.3, 2.5 and 2.6) The most notable differences appear between manufacturers. (See Figures 2.7-2.11) Within a rating scheme of 0-10, 10 being perfect, one manufacturer had an overall performance rating of 9.8; whereas, another had an overall average of 5.4. Note differences shown in Figure 2.5. What this really demonstrates is that

a prospective customer must know the capabilities of the company supplying various materials. Figure 2.1 shows a dramatic difference between two suppliers marketing the same coating system.

It is extremely wise to perform simple screening tests on candidate materials, or require verifiable case histories, where the product under consideration was used under similar conditions. No new ship should be the

proving grounds for new, unproved, untested materials. Many shipbuilders can bear testimony to the cost associated with this act. Figures 2.3 thru 2.6 contain a pictorial representation of supplier versus supplier rankings of various coatings systems as noted on the figure description. Figures 2.7 thru 2.11 are a pictorial representation comparing the same generic paint system supplied by various suppliers.

TABLE VIII: Paint Systems Tested

SUPPLIER CODE	SYSTEM COAT	FIRST COAT		SECOND COAT		THIRD COAT		FOURTH COAT	
		Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)
A	A-1	Alkyl Inorganic Zinc	3.0 - 5.0	Synthetic Tie Coat	1.0 - 1.5	Vinyl Chloride Copolymer	1.3 - 1.7	Vinyl Chloride Copolymer	1.0 - 3.0
A	A-2	" "	3.0 - 6.0	" "	0.5 - 1.0	Modified Acrylic	1.5 - 3.0	NONE	
A	A-3	" "	3.0 - 6.0	Polyamide Epoxy	3.0	Polyamide Epoxy	3.0 - 6.0	NONE	
A	A-4	" "	3.0 - 7.0	" "	2.5 - 3.0	"	2.5 - 5.0	NONE	
A	A-5	" "	3.0 - 6.0	"	2.0 - 4.0	Gloss Silicone Alkyd	1.7 - 3.0	Gloss Silicone Alkyd	1.0 - 1.7
A	A-6	" "	3.0 - 6.0	"	2.5 - 4.0	Aliphatic polyurethane	1.7 - 4.5	Aliphatic polyurethane	2.0 - 3.7
A	A-7	" "	3.0 - 5.0	Chlorinated Rubber	2.0 - 3.0	Chlorinated Rubber	1.0 - 2.3	Chlorinated Rubber	2.5 - 3.8
B	B-1	" "	3.0 - 8.0	Vinyl Copolymer Tie coat	1.0 - 2.5	Vinyl Copolymer	1.5	Vinyl Copolymer	2.5 - 4.0
B	B-2	" "	3.0 - 9.0	Polyamide Epoxy	5.0 - 6.0	Mod. Medium Oil Alkyd	2.0 - 3.0	Mod. Medium Oil Alkyd	2.0
B	B-3	" "	8.0	"	6.0 - 9.0	Aliphatic polyurethane	3.0 - 4.0	Aliphatic polyurethane	3.0 - 4.5
B	B-4	" "	4.0 - 8.0	Chlorinated Rubber	2.0 - 3.0	Chlorinated Rubber	1.0	Chlorinated Rubber	2.0 - 3.5
C	C-1	" "	3.0 - 6.0	Vinyl Tie coat	2.0 - 4.0	Vinyl Acrylic	1.0 - 4.0	Vinyl Acrylic	2.0 - 3.0
C	C-2	" "	4.0 - 7.0	Polyamide Epoxy	11.0 - 15.0	NONE		NONE	
C	C-3	" "	6.0 - 7.0	"	10.0 - 14.0	Gloss Silicone Alkyd	2.0 - 4.0	Gloss Silicone Alkyd	2.0 - 4.0
C	C-4	" "	3.0 - 6.0	"	7.0 - 8.0	Acrylic Epoxy	6.0 - 8.0	NONE	

(continued on next page)

TABLE VIII: Paint Systems Tested (continued)

SUPPLIER CODE	SYSTEM COAT	FIRST COAT		SECOND COAT		THIRD COAT		FOURTH COAT	
		Generic Type	Film Thick (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)
D	D-1	Alkyl Inorganic Zinc	3.0 - 5.0	Polyamide Epoxy	2.7 - 3.0	Polyamide Epoxy	3.3 - 4.0	NONE	
D	D-2	" "	3.0 - 6.0	"	3.0 - 3.5	Alkyd	1.5 - 3.0	NONE	
D	D-3	" "	2.6 - 5.0	"	3.2 - 3.8	Silicone Alum (High Heat)	2. - 3.0	NONE	
E	E-1	" "	4.0 - 7.0	Vinyl Acrylic Tie coat	1.3 - 3.4	Vinyl Acrylic	3.0 - 5.0	NONE	
E	E-2	" "	4.0 - 6.5	Polyamide Epoxy	5.0 - 6.8	NONE			
E	E-3	" "	4.5 - 7.0	"	5.0 - 9.0	Alkyd	3.0 - 5.0	NONE	
E	E-4	" "	4.5 - 6.0	"	6.0	Silicone Alkyd	1.	NONE	
E	E-5	" "	3.0 - 7.0	"	5.5 - 7.0	Aliphatic polyurethane	2.0 - 2.5	NONE	
E	E-6	" "	4.0 - 5.0	Vinyl Acrylic Tie coat	2.5 - 3.0	Chlorinated Rubber Acrylic	2.0 - 2.8	NONE	
F	F-1	" "	2.0 - 7.0	Vinyl	2.0	Vinyl Acrylic	1.5	Vinyl Acrylic	1.5
F	F-2	" "	2.5 - 3.6	Vinyl Wash Primer	1.0	Aliphatic polyurethane	1.5 - 2.5	Aliphatic polyurethane	1.0 - 3.5
F,	F-3	" "	2.3 - 3.6	" "	(.75	Aromatic polyurethane	2.5 - 3.5	Aromatic polyurethane	1.0 - 2.0
F	F-4	" "	2.5 - 7.0	Polyamide Epoxy	8.0 - 16.0	NONE			
G	G-1	" "	1.0 - 2.0	Polyvinyl Chloride	1.6	Polyvinyl Chloride	2.6 - 5.0	NONE	
G	G-2	" "	1.0 - 2.3	Polyamide Epoxy	6.0 - 7.0	Polyamide Epoxy	2.0 - 4.0	NONE	
G	G-3	" "	1.0 - 2.4	" "	6.2 - 7.0	Alkyd Tie coat	2.2 - 3.0	NONE	
G	G-4	Phenolic Mod Alkyd Primer	3.0	Alkyd	2.5	Alkyd	2.5		2.5 - 4.0

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TABLE VIII: Paint Systems Tested (continued)

SUPPLIER CODE	SYSTEM COAT	FIRST COAT		SECOND COAT		THIRD COAT		FOURTH COAT	
		Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)
G	G-5	Alkyl Inorganic Zinc	1.0 - 2.4	Polyamide Epoxy	6.0 - 7.0	Polyvinyl Chloride	4.2 - 5.0	NONE	
G	G-6	" "	1.1 - 2.3	Chlorinated Rubber	2.0	Chlorinated Rubber	2.2 - 3.5	NONE	
H	H-1	" "	2.0 - 2.2	Vinyl	0.6	Vinyl	3.0 - 5.0	Vinyl	1.5 - 3.2
H	H-2	" "	1.7 - 2.5	Polyamide Epoxy	4.5 - 6.5	Polyamide Epoxy	1.6 - 5.0	NONE	
H	H-3	" "	1.7 - 2.4	"	6.0 - 9.0	Alkyd	1.5 - 2.8	NONE	
H	H-4	" "	1.7 - 2.4	"	5.3 - 9.0	Aliphatic Urethane	2.8 - 3.0	NONE	
H	H-5	" "	1.7 - 2.0	"	6.0 - 8.0	Water Borne Acrylic	1.5 - 3.0	NONE	
H	H-6	" "	1.7 - 2.4	Chlorinated Rubber	2.4 - 4.8	Chlorinated Rubber	2.8 - 4.1	NONE	
I	I-1	" "	4.5	Copolymer Tie coat	1.2 - 1.8	Vinyl Copolymer	2.0	NONE	
I	I-2	" "	4.5	Vinyl Copolymer	2.3	Vinyl Copolymer	2.3	NONE	
I	I-3	" "	5.5 - 5.7	Catalyzed Epoxy	2.0 - 5.0	NONE			
I	I-4	" "	3.4 - 4.9	Polyamide Epoxy	2.4 - 4.5	Alkyd	1.0	NONE	
I	I-5	" "	5.4 - 5.8	Chlorinated Rubber	2.0 - 3.0	Chlorinated Rubber	1.0 - 2.6	NONE	
I	I-6	" "	5.7	Polyamide Epoxy	1.6	Urethane	2.5	NONE	
I	I-7	" "	5.4 - 5.7	High Build Urethane	1.1 - 3.4	Urethane	1.3 - 3.5	NONE	

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TABLE VIII: Paint Systems Tested (continued)

SUPPLIER CODE	SYSTEM COAT	FIRST COAT		SECOND COAT		THIRD COAT		FOURTH COAT	
		Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)	Generic Type	Film Thick. (Mil.)
J	J-1	Alkyl Inorganic Zinc	4.8	Vinyl Wash Primer	0.5	Polyvinyl Chloride	2.8	NONE	
J	J-2	" "	2.5 - 4.8	"	0.5	Aliphatic Polyurethane	2.0	NONE	
K	K-1	" "		High Build Vinyl		NONE			
K	K-2	" "		Epoxy		NONE			
K	K-3	" "		Epoxy		Alkyd		NONE	
K	K-4	" "		Epoxy		Aliphatic Polyurethane		NONE	
K	K-5	" "		Chlorinated Rubber		Chlorinated Rubber		NONE	
L	L-1	Modified Alkyl Inorganic Zinc	2.3 - 4.2	Polyamide Epoxy	4.5 - 5.0	Polyamide Epoxy	3.6 - 7.8	NONE	
L	L-2	" "	2.0 - 3.8	"	4.4 - 6.6	Silicone Alkyd	1.0 - 2.8	NONE	
L	L-3	" "	2.5 - 4.5	"	3.3 - 7.4	Aliphatic Polyurethane	2.0 - 3.0	NONE	
L	L-4	" "	2.5 - 4.2	Chlorinated Rubber	3.5 - 4.0	Chlorinated Rubber	3.0 - 4.5	NONE	

**TABLE IX: Comparison of Corrosion Resistance of Various
Generic Types of Exterior Marine Paint Systems After 2000 HR Salt Spray Testing
(Rated in Accordance with ASTM D610-6B-10 is Perfect)**

Supplier vs. Supplier Figures	System	Inorganic Zinc Plus Epoxy		Inorganic Zinc Epoxy Plus Alkyd		Inorganic Zinc Epoxy + Urethane		Inorganic Zinc Plus Vinyl		Inorganic Zinc + Chlor. Rubber		Inorganic Zinc Plus Other		Supplier Average Perform.
	'Supplier Code	Sys. Code	Rating	Sys. Code	Rating	Sys. Code	Rating	Sys. Code	Rating	Sys. Code	Rating			
2.3	A	A-3	10	A-5	9	A-6	10	A-1	9	A-7	10			
	A	A - 4	9					A-2	9					9.4
	B			B-2	9	B-3	9	B-1	9	B-4	9			9.0
	C	C-2	10	C-3	9			C-1	9			Epoxy + epoxy acry- lic C-4	10	9.5
2.4	D	D-1	9	D-2	8									8.5
	E	E-2	10	E-3	9	E-5	10	E-1	10					
	E			E-4	10									9.8
	E	F-4	10			F-2	10	F-1	9					9.75
2.5	F					F-3	10							
	G	G-2	Compl. failed @ 200 hrs	G-3	9			G-1	9	G-6	9	Epoxy plus vinyl G-5	Compl. failed	5.4
	H	H-2	9	H-3	8	H-4	8	H-1	8	H-6	6	Epoxy plus water borne acrylic H-5	8	7.8
2.6	I	I-3	9	I-4	9	I-7	9	I-1	8	I-5	9			9.0
	J					J-2	9	J-1	8					8.5
	K	K-2	6	K-3	6	K-4	9	K-1	9	K-5	6			7.2
	L	L-1	8	L-2	8	L-3	9			L-4	9			8.5
	System Average Performance		9		8.5		9.3		8.9		8.3			
	System vs. System Figs.	2.7		2.8		2.9		2.10		2.11				

TABLE X: Comparison of Gloss Retention (% Change in Gloss) and Chalking Resistance (Jacobson Chalk Rating) of Various Generic Types of Exterior Marine Paint Systems Applied Over an Alkyl Inorganic Zinc Primer and Exposed to (1) 1000 Hours in a Carbon Arc Weather-Ometer (ASTM D822) and (2) Exterior Test Rack -45° South. A Chalk Rating of 10 Represents NO Chalking. (See Figure 2.12)

	PRIMER PLUS EPOXY			PRIMER; EPOXY PLUS SILICONE ALKYD			PRIMER, EPOXY PLUS ALKYD			PRIMER, EPOXY PLUS ALIPHATIC URETHANE			PRIMER PLUS VINYL			PRIMER PLUS CHLORINATED RUBBER			PRIMER PLUS OTHER		
	System	Gloss	Chalk	System	Gloss	Chalk	System	Gloss	Chalk	System	Gloss	Chalk	System	Gloss	Chalk	System	Gloss	Chalk	System	Gloss	Chalk
(1)	A-4	82%	6.0	A-5	67%	10	B-2	82%	9.5	A-6	35%	10.0	A-1	N.R.	9.0	A-7	61%	9.0	A-2	41%	10
(2)		87%	6.0		15%	9.5		49%	8.0		23%	9.5		Flat	N.R.		48%	8.0		0%	10
(1)	D-1	96%	2.0	D-3	17%	10	D-2	89%	9.0	B-3	N.R.	N.R.	B-1	78%	9.5	B-4	87%	9.5	E-1	N.R.	9.5
(2)		99%	4.0		22%	8.0		78%	8.0		14%	9.0		36%	9.0		90%	8.0		Flat	9.0
(1)	E-2	N.R.	6.0	E-4	63%	9.5	E-3	77%	9.0	E-5	28%	10.	G-1	N.R.	9.0	E-6	66%	9.0	F-1	67%	9.0
(2)		Flat	4.0		33%	9.0		34%	8.0		13%	8.5		Flat	4.0		33%	8.0		63%	8.0
(1)	C-2	92%	4.0	C-3	50%	10.	G-3	70%	9.0	H-4	50%	10	H-1	72%	9.0	G-6	N.R.	9.5	C-1	53%	10.
(2)		92%	2.0		5%	9.5		53%	9.0		21%	9.0		63%	9.0		Flat	8.0		0%	10.
(1)	F-4	86%	6.0	L-2	66%	9.5	H-3	84%	9.5	F-2	29%	10	K-1	N.R.	9.0	H-6	84%	9.5	C-4	94%	9.0
(2)		84%	6.0		28%	9.5		34%	9.0		32%	9.5		Flat	8.0		0%	9.5		92%	9.0
(1)	G-2	60%	4.0				K-3	93%	9.0	K-4	32%	10.	J-1	N.R.	N.R.	K-5	81%	9.5	F-3	84%	8.0
(2)		83%	2.0					84%	9.0		28%	9.5		Flat	6.0		31%	9.5		13%	9.5
(1)	H-2	64%	4.0							L-3	26%	10				L-4	92%	9.5	H-5	51%	10.
(2)		97%	2.0								0%	10					55%	9.5		35%	9.0
(1)	K-2	91%	4.0							J-2	42%	10									
(2)		95%	6.0								17%	10									
(1)	L-1	95%	2.0							I-7	N.R.	N.R.	I-2	N.R.	N.R.						
(2)		92%	2.0								12%	10		Flat	9.5						
(1)	I-3	N.R.	N.R.				I-4	N.R.	N.R.	I-6	N.R.	N.R.	I-1	N.R.	N.R.	I-5	N.R.	N.R.			
(2)		91%	6.0					77%	10		2%	9.5		Flat	9.5		41%	9.5			
(1)	Averages	83.3%	4.2		52.6%	9.8		82.5%	9.2		34.6%	10		75%	9.1		78.5%	9.4		N/A	N/A
(2)	Averages	91.1%	4.4		20.6%	9.1		58.4%	8.7		16.2%	9.5		49.5%	7.9		42.6%	8.8		N/A	N/A

2.7 Life Cycle Cost Determination

With the enlargement of the data bank, two important pieces of information can be obtained, namely, percent failure per time period and expected system life. The percent failure per time period is an expression of required maintenance. The expected system life is the projected life of the paint system with maintenance until such time as a complete replacement is warranted due to extensive maintenance cost.

From the above information the life cycle cost of a paint system can be determined. From a comparison of life cycle cost, the lowest can be determined and a paint system selection can be made. When calculating life cycle cost it must be remembered that the lowest initial cost may or may not be the least expensive overall. It is entirely possible that the system demonstrating the best performance is also the most expensive initially.

The first step in a life cycle cost calculation is to determine the required life of the paint system which is predicated on the designed useful life of the ship. No paint system will last for the entire life of the ship; therefore, consideration must be given to initial cost, maintenance cost, and replacement cost at designated intervals. Several techniques exist for economic appraisal of alternates. Among these are "Discounted Cash Flow", "Return on Investment", and "pay-out period". The National Association of Corrosion Engineers, 2400 West Loop South, Houston, Texas has a recommended practice entitled "*Direct Calculations of Economic Appraisals of Corrosion Control Measures*", NACE Standard RP-02-72-748. *The discussion which follows was taken in part from this document. Copies of this Standard are available for purchase from NACE at a nominal charge. Other reference materials are also available (see bibliography 79,84 and 88).*

At this time it may be useful to define some terms.

1. Life Cycle Cost (ICC) — This is the anticipated cost of the vessel over a defined time period expressed as cash flow. Life may constitute projected duration of the vessel life, or an artificial period of depreciation or depletion calculated for accounting purposes.
2. Expected System Life (ESL) — The projected life of the paint system with maintenance until such time as a complete replacement is warranted due to extensive maintenance costs.

3. Negative Cash Flow — The actual cost of a particular system to include materials and labor for both initial installation, maintenance and system replacement.
4. Positive Cash Flow — Income.
5. Present Worth After Taxes (PWAT) — The "now" value or Present Worth After Taxes is obtained by correcting any cash flow or flows, now or in the future, for all taxes and tax allowances.
6. Annual Cost (A) — The equivalent uniform cost beginning one year hence or "end of year".
7. d: — Tax and depreciation factor equal to the PWAT of \$1.00 depreciated at the applicable schedule and taxed at the applicable rate, expressed in cents on the dollar (or decimal). Usually obtained from a table.
8. F — Variant from Capital Recovery Factor. Usually obtained from a table.
9. r — Rate of return after taxes, as a decimal. Usually obtained from a table.
10. Design Life (DL) — Duration of the designed life of the vessel.

As stated earlier, the first step is to determine the design life of the ship. This is generally accepted as being twenty years. The next step is to determine the expected life of each candidate system (ESL). This is determined from an analysis of the paint service histories data bank.

The next step is to determine the initial material and labor cost per square foot to include surface preparation. There are many references which contain standard man hours for various labor operations. Labor cost can also be obtained from published documents. Material cost and coverage rates can be obtained from the coatings suppliers. Material cost in dollars, divided by the coverage rate expressed in square feet, results in a dollar per square foot rate.

Maintenance cost can be determined from the projected percent failure per year obtained from the service histories data bank. This one variable is the most important of the entire calculation. Without this information, the remainder of this evaluation would be meaningless.

Using standard economic formulas and tables, the annual cost of each system can be calculated. This cost data is then multiplied by the design life of the ship to arrive at Life Cycle Cost (LCC). Listed below is one approach which can be used.

$$LCC = DL \cdot A$$

$$A = PWAT \cdot r \cdot F_n$$

$$PWAT = \frac{adY}{(1+r)^m}$$

where LCC = Life Cycle Cost

DL = Design Life

A = Annual Cost

PWAT = Present Worth After Taxes

r = Rate of Return After Taxes

F = Variant from Capital Recovery Factor
= any cash flow in dollars

d = Tax & Depreciation Factor

Y = Write-off or depreciation period in years

n = Life of ship in years

m = Time to occurrence of cash flow in years

Example: Two paint systems are being compared. System Ø costs \$1.00 per square foot applied and has a projected life of ten years with a maintenance touchup of 5% after five years. System ψ costs \$0.50 per square foot applied and has a projected life of five years with no touchup scheduled. The ship has a design life of twenty years.

Assumptions: (1) First year is capitalized
(2) Inflation rate of 6% per year
(3) Irregular sum-of-digits depreciation
(4) Tax rate = 48%
(5) Money is worth 10% after taxes
(6) First year is year zero.

$$A_{\emptyset} = PWAT_{\emptyset \text{ Total}} \times r \times F_{20}$$

$$A_{\psi} = PWAT_{\psi \text{ Total}} \times r \times F_{20}$$

$$PWAT_{\emptyset \text{ Total}} = PWAT_{\emptyset 1} + PWAT_{\emptyset 2}$$

$$\begin{aligned} PWAT_{\emptyset 1} &= -\$1.00/\text{ft}^2 \times d_{19} - \frac{\$1.69/\text{ft}^2 \times d_1 \times F_{10}}{(1+r)^{10}} \\ &= -\$1.00/\text{ft}^2 \times .64 - \frac{\$1.69/\text{ft}^2 \times .52 \times 1.627}{2.595} \\ &= -\$1.19/\text{ft}^2 \end{aligned}$$

$$\begin{aligned} PWAT_{\emptyset 2} \text{ (Maintenance)} &= -(0.05 \times \$1.26/\text{ft}^2 \times d_1) - (0.05 \times \$1.69/\text{ft}^2 \times d_1) \\ &= -(0.05 \times \$1.26/\text{ft}^2 \times .52) - (0.05 \times \$1.69/\text{ft}^2 \times .52) \\ &= -\$0.12/\text{ft}^2 \end{aligned}$$

$$PWAT_{\emptyset \text{ Total}} = \$1.19/\text{ft}^2 - \$0.12/\text{ft}^2 = -\$1.31/\text{ft}^2$$

$$\begin{aligned} PWAT_{\psi 1} &= -\$0.50/\text{ft}^2 \times d_{19} - \frac{\$0.63/\text{ft}^2 \times .52 \times \frac{F_{10}}{F_{15}}}{(1+r)^5} - \\ &= \frac{\$0.85/\text{ft}^2 \times 0.52 \times \frac{F_{10}}{F_{15}}}{(1+r)^{10}} = -\$0.85/\text{ft}^2 \end{aligned}$$

$$PWAT_{\psi 2} \text{ (Maintenance)} = 0$$

$$PWAT_{\psi \text{Total}} = -\$0.85/\text{ft}^2 - \$0 = \$0.85/\text{ft}^2$$

$$A_{\emptyset} = PWAT_{\emptyset \text{Total}} \times r \times F_{20} = -\$1.31 \times .1 \times 1.175 = -\$0.15/\text{ft}^2/\text{year}$$

$$A_{\psi} = PWAT_{\psi \text{Total}} \times r \times F_{20} = -\$0.85 \times .1 \times 1.175 = -\$0.10/\text{ft}^2/\text{year}$$

$$\text{System } \emptyset \text{ LCC} = -\$0.15/\text{ft}^2/\text{year} \times 20 \text{ years} = -\$3.00/\text{ft}^2$$

$$\text{System } \psi \text{ LCC} = -\$0.10/\text{ft}^2/\text{year} \times 20 \text{ years} = -\$2.00/\text{ft}^2$$

From this analysis it can be seen that System ψ is the most cost effective. Different values for square foot cost would result in different results. Each case must be evaluated separately.

Antifouling Systems cost effectiveness must also

take into account frictional resistances and fuel consumption. There are many excellent papers on this subject. (6, 55, 78). One is "*The Economy of Smooth Hulls*" by H. Hacking, Principal Research Officer, Measurement Section, British Ship Research Association. (126).

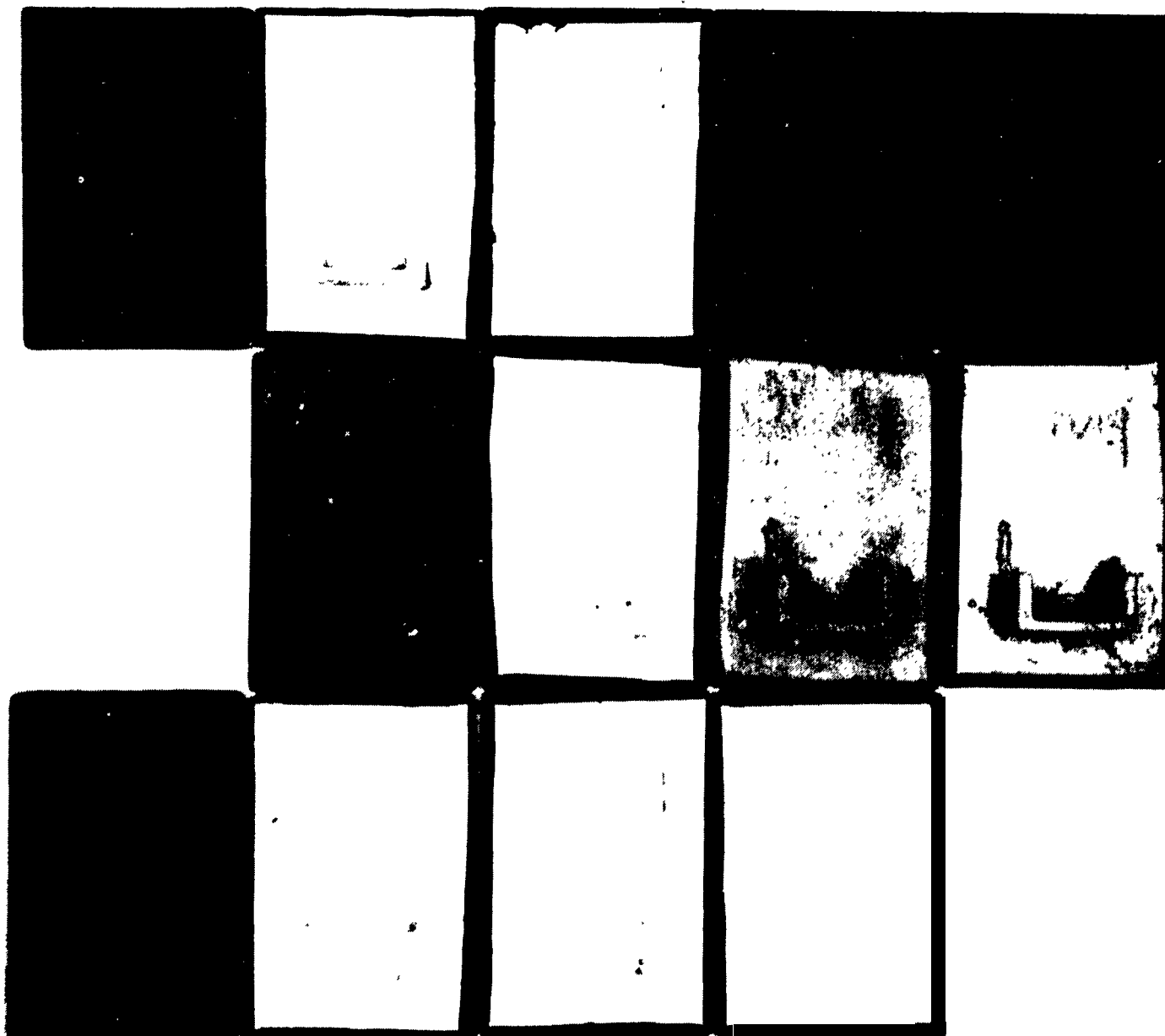
Tables IX and X contain the results of the tests referred to in section 2.6.5. The system numbers listed in Table VIII are noted on the layout diagrams which precede each of the following photographs. The reader can match the alpha-numeric code on each layout with the same position on the corresponding photograph and then refer back to table VIII to find the exact system information.



**FIGURE 2.2: Uncoated Control Panels After 2000 Hours
in Synthetic Sea Water-Salt Spray Cabinet**

Inorganic Zinc/ EPOXY	Inorganic Zinc/Epoxy/ Alkyd	Inorganic Zinc/Epoxy/ Polyurethane	Inorganic Zinc/Vinyl	Inorganic Zinc/ chlorinated Rubber
A-3	A-5	A-6	A-1	A-7
	B-2	B-3	B-1	B-4
c-2	c-3	c-4 Epoxy Acrylic	c-1	

Panel layout for Figure 2.3



**FIGURE 2.3: Supplier Codes A, B, C Paint Systems After 2000 Hours
in Synthetic Sea Water-Salt Spray Cabinet**

Inorganic Zinc/Epoxy	Inorganic Zinc/Epoxy/ Alkyd	Inorganic Zinc/Epoxy/ Polyurethane	Inorganic Zinc/Vinyl
D-1	D-3		
E-2	E-4	E-5	E - 1
F-4		F-2 Wash Primer Topcoat	Fig. 2.11 *D-2 Fig. 2.15 F-1 *(Alkyd in Photo by Mistake)

Panel layout for Figure 2,4

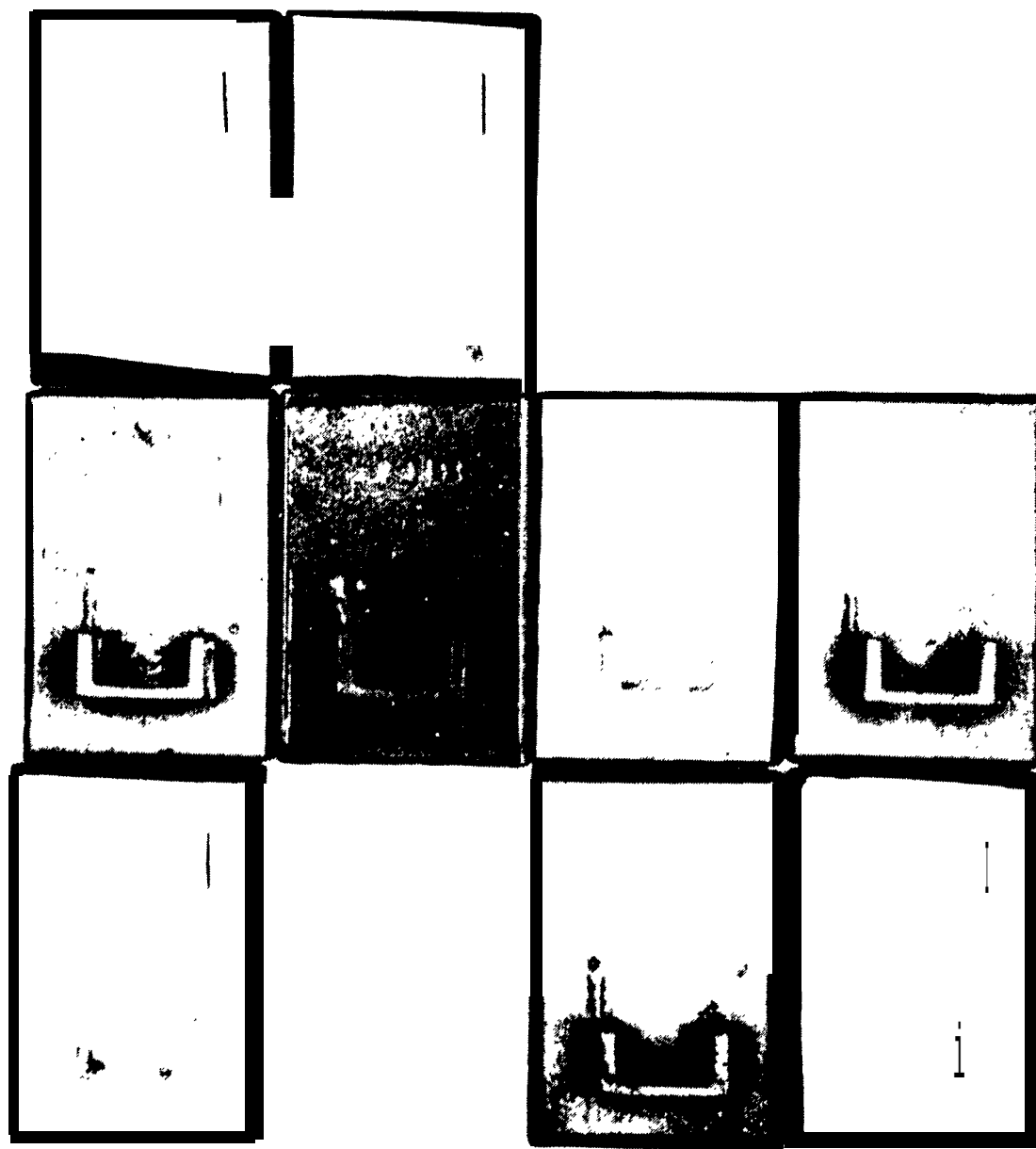


FIGURE 2.4: Supplier Codes D, E, F Paint Systems after 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc/Epoxy	Inorganic Zinc/Epoxy/ Alkyd	Inorganic Zinc/Epoxy/ Polyurethane	Inorganic Zinc/Vinyl	Inorganic Zinc/ Chlorinated Rubber
G-2	G-3		G-1	G-6
H-2	H-3	H-4	H-1	H-6
I-3	I-4	High Build Urethane Intermediate	I-1	

Pa Layout for Figure 2.5



FIGURE 2.5: Supplier Codes G, H, I Paint Systems After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc/Epoxy	Inorganic Zinc/Epoxy/ Alkyd	Inorganic Zinc/Epoxy/ Urethane	Inorganic Zinc/Vinyl	Inorganic Zinc/ Chlorinated Rubber
		J-2 Wash Primer Tie Coat	J-1	I-5
K-3	K-3	K-4	K-1	K-5
L-1	L-2	L-3		L-4

Panel Layout for Figure 2.6

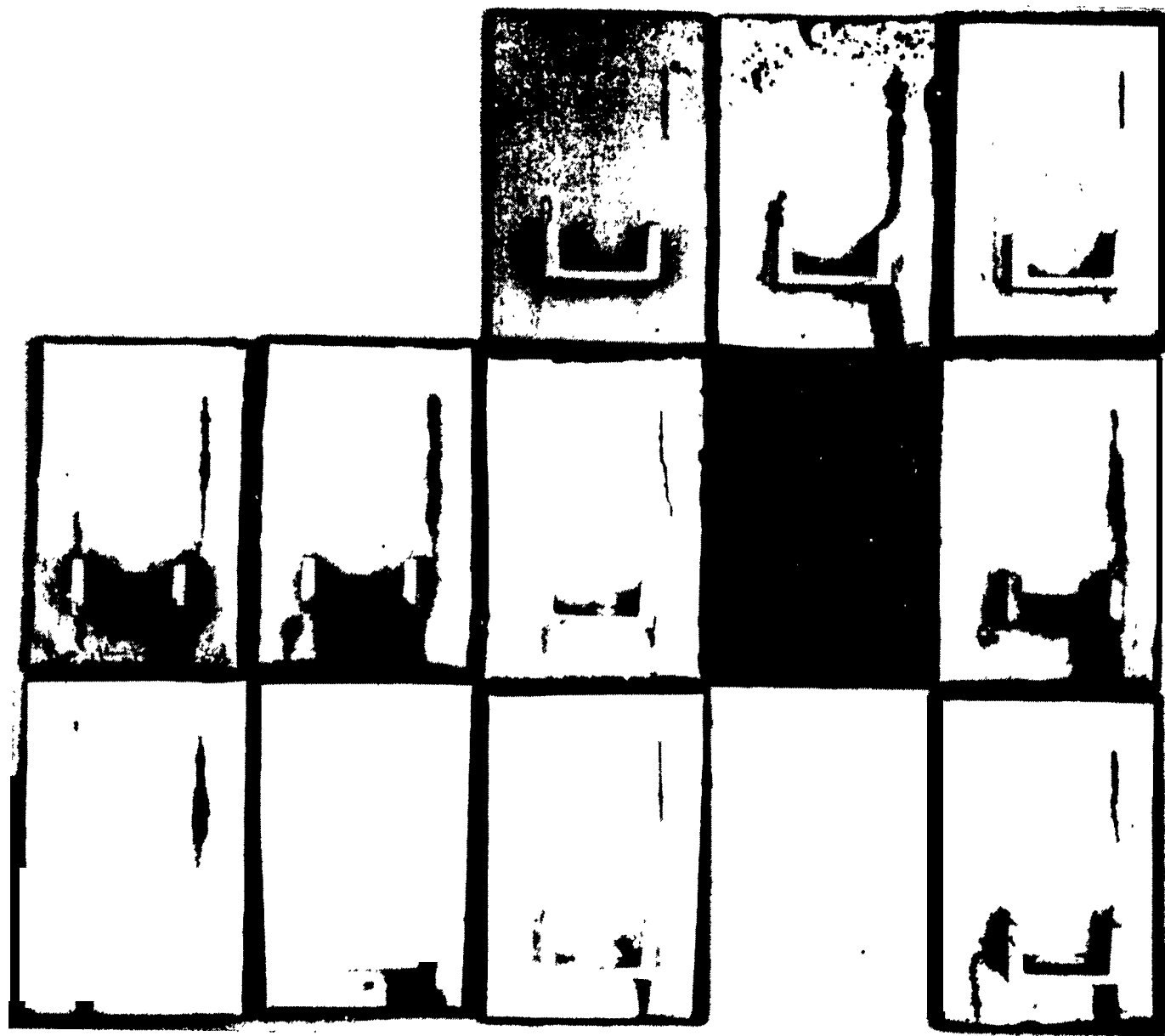


FIGURE 2.6: Supplier Codes J, K, L Paint Systems after 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc, Polyamide Epoxy Paint Systems
From Various Suppliers

A-3	c-2	D-1	E-2	F-4
G-2	H-2	I - 3	K-2	L-1

Panel layout for Figure 2.7

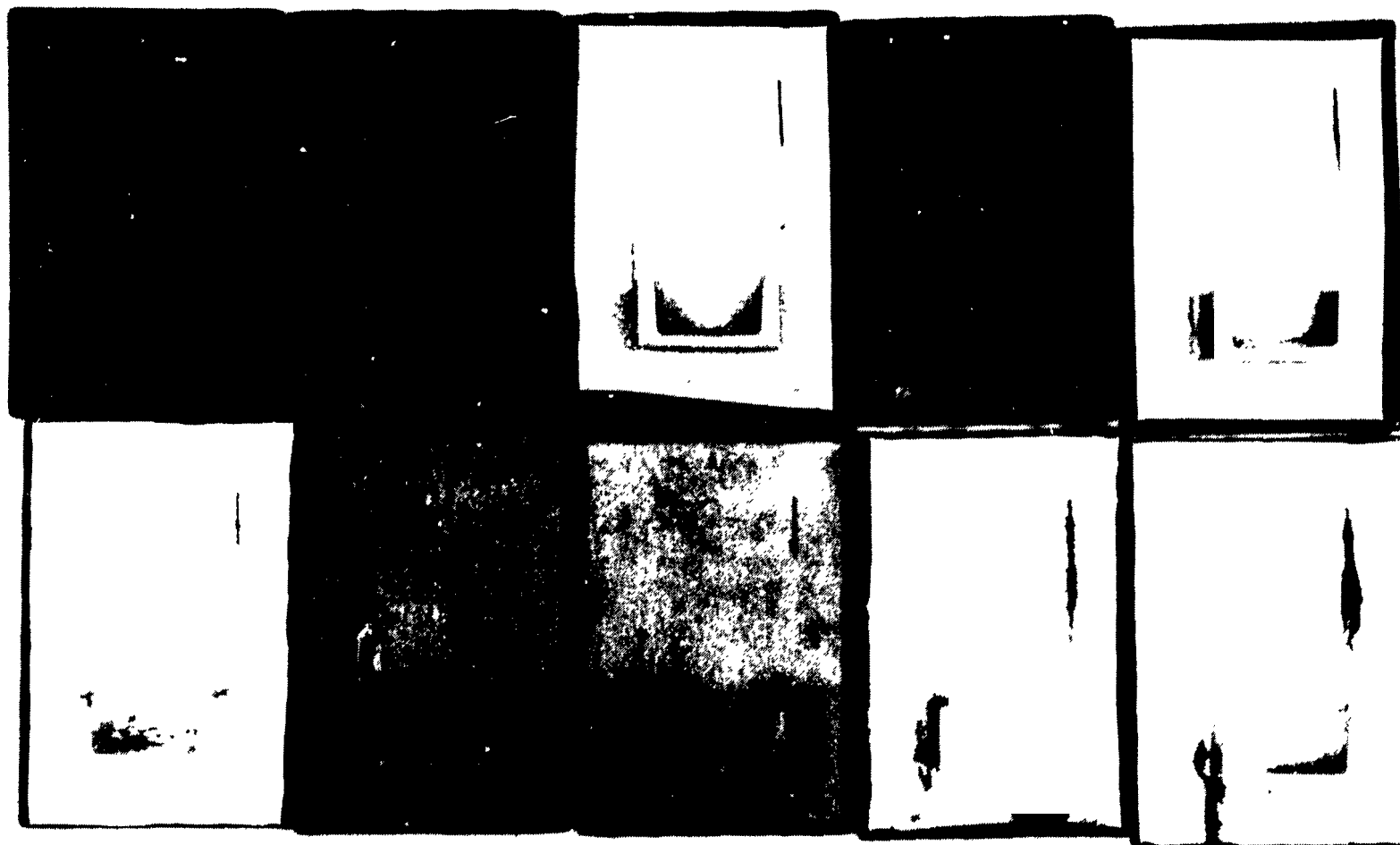


FIGURE 2.7: Inorganic Zinc, Polyamide Epoxy Paint Systems from Various Suppliers After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc, Polyamide Epoxy, Alkyd Paint Systems
From Various Suppliers

A-5	B-2	c-3	D-3	E-4
G-3	H-3	I-4	K-3	L-2

Panel layout for Figure 2.8

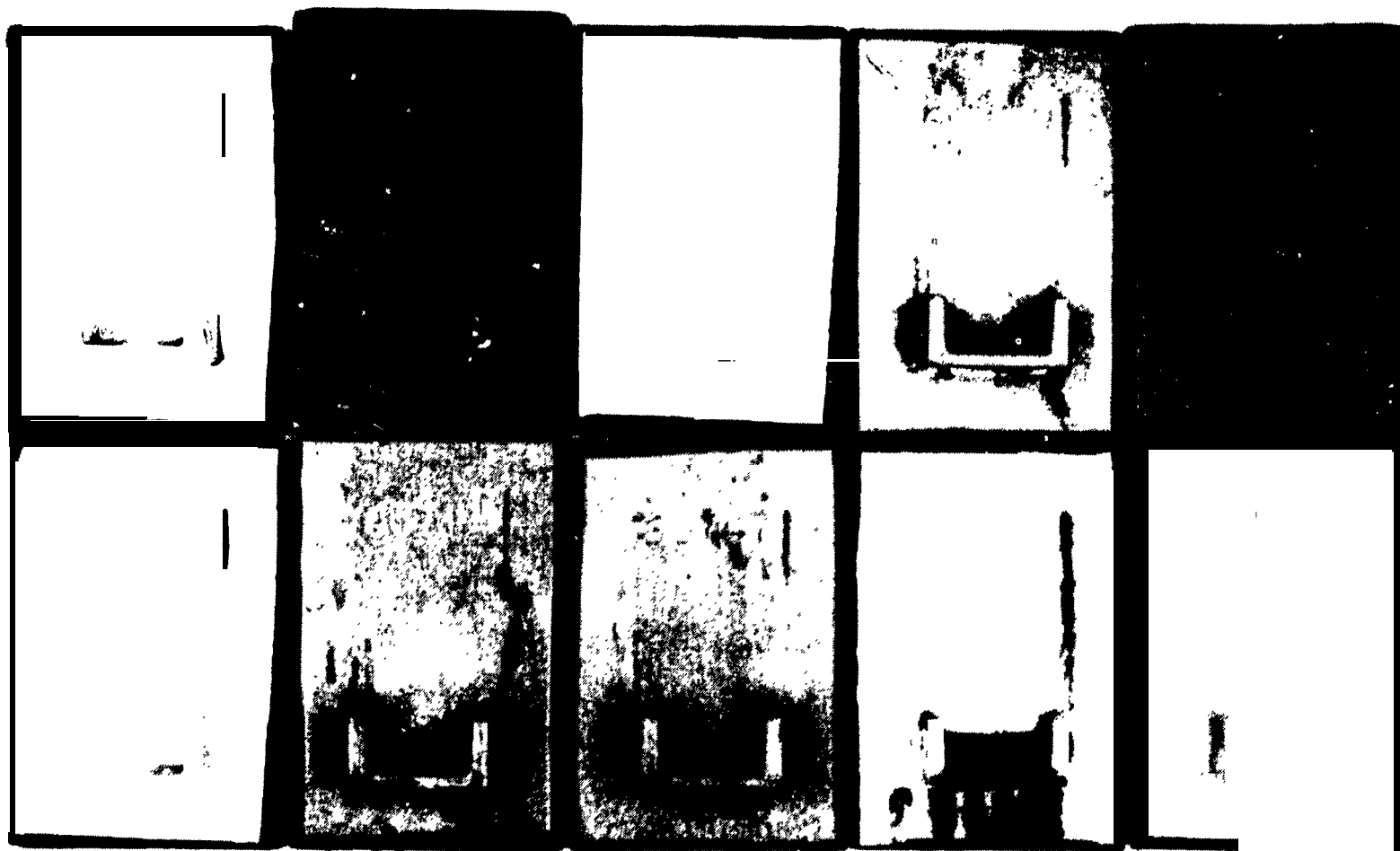


FIGURE 2.8: Inorganic Zinc, Polyamide Epoxy, Alkyd Paint Systems from Various Suppliers After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc, Polyamide Epoxy, Polyurethane Paint
Systems From Various Suppliers

A-6	B-3	C-4 Epoxy Acrylic	E-5	F-2 Wash Primer Top Coat
H-4	I-7	J-2	K-4	L-3

Panel Layout for Figure 2.9

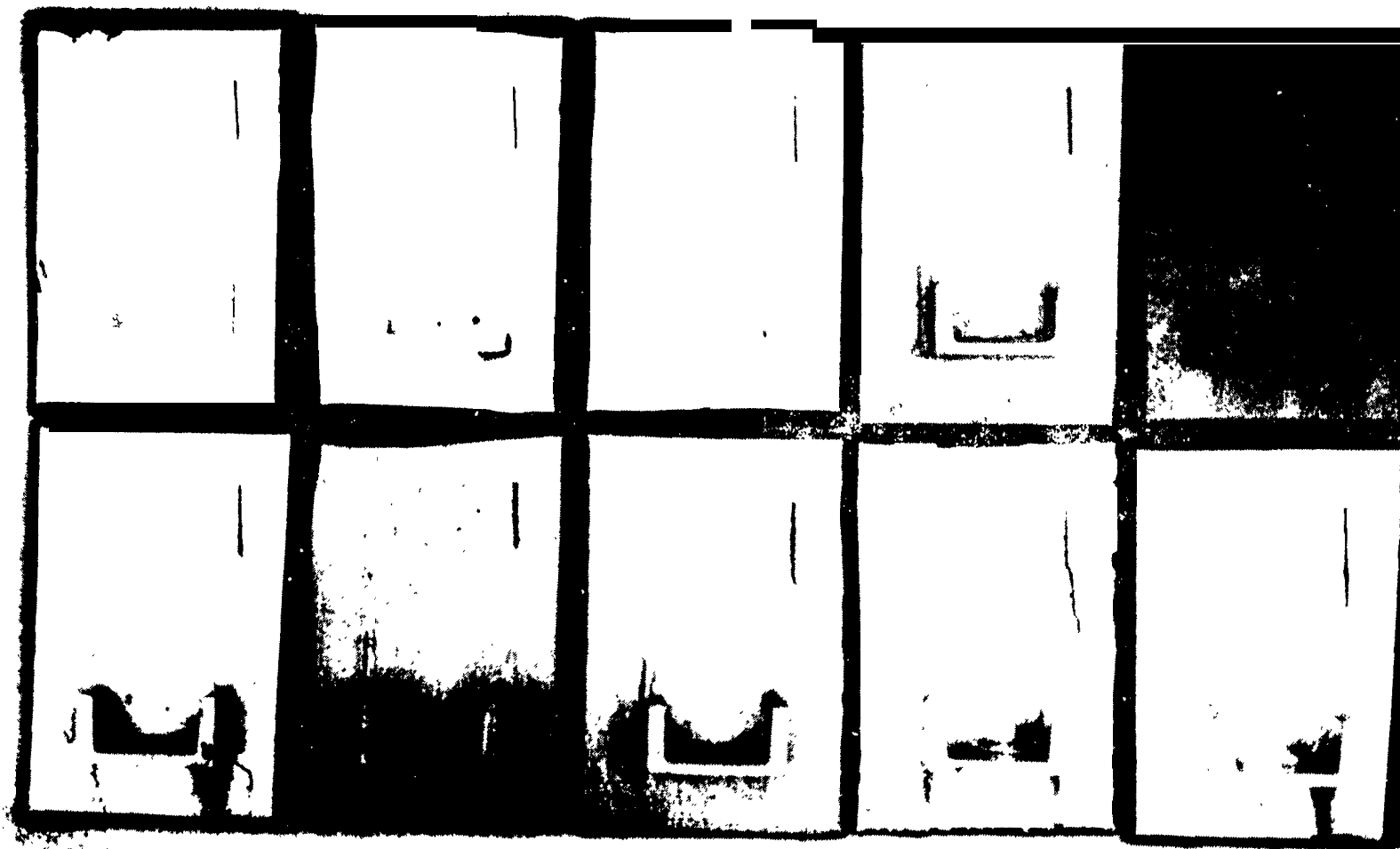


FIGURE 2.9: Inorganic Zinc, Epoxy, Polyurethane Paint Systems from Various Suppliers After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

Inorganic Zinc, Vinyl Paint Systems From
Various Suppliers

A-1	B-1	c-1	E-1	D-2 (Alkyd in photo by mistake)
G-1	H-1	1-1	J-1	K-1

Panel layout for Figure 2.10

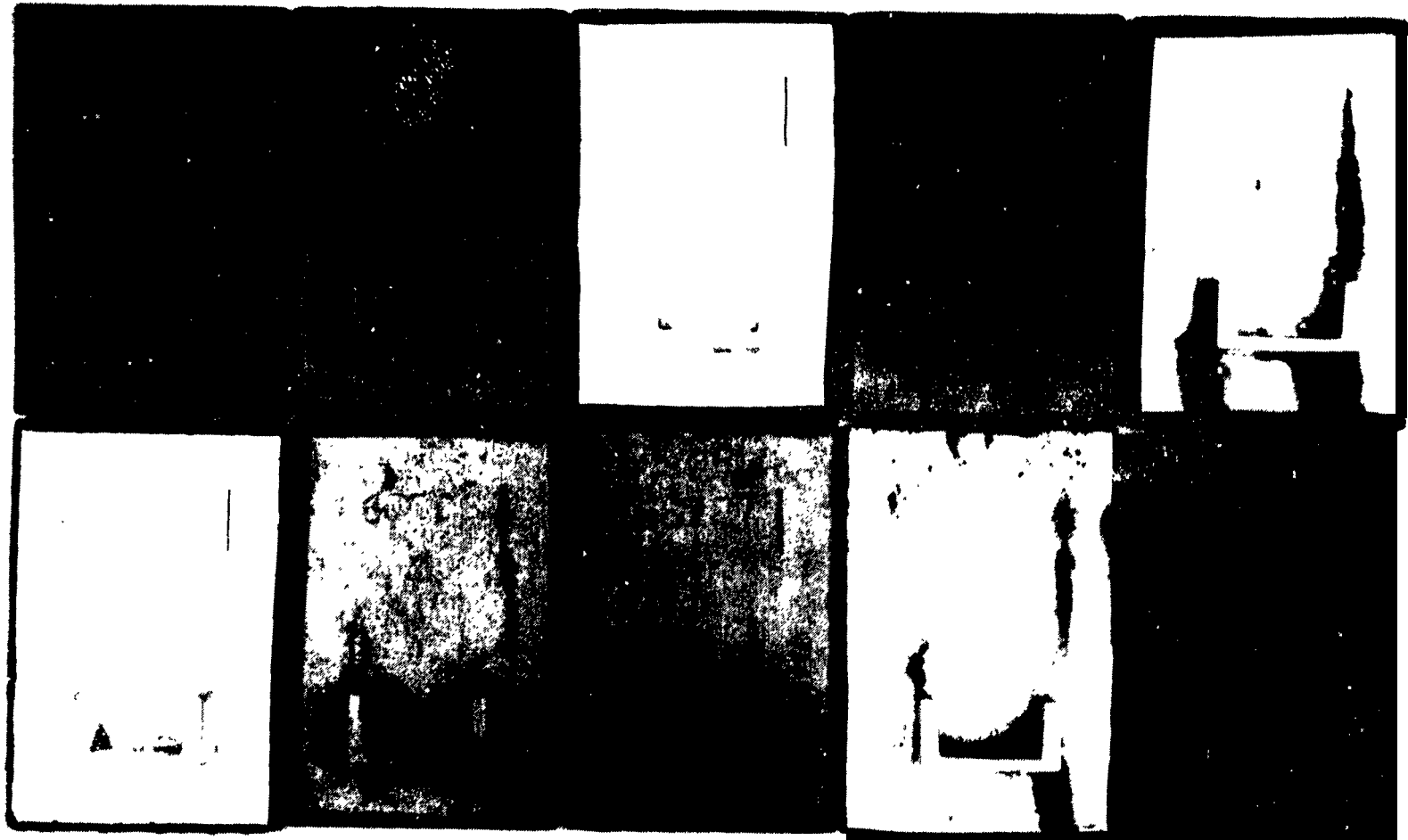


FIGURE 2.10: Inorganic Zinc, Vinyl Paint Systems from Various Suppliers
After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet

norganic Zinc, Chlorinated Rubber Paint Systems
From Various Suppliers

A-7	B-4	G-6	H-6	I-5
	L-4			

Panel Layout for Figure 2.11

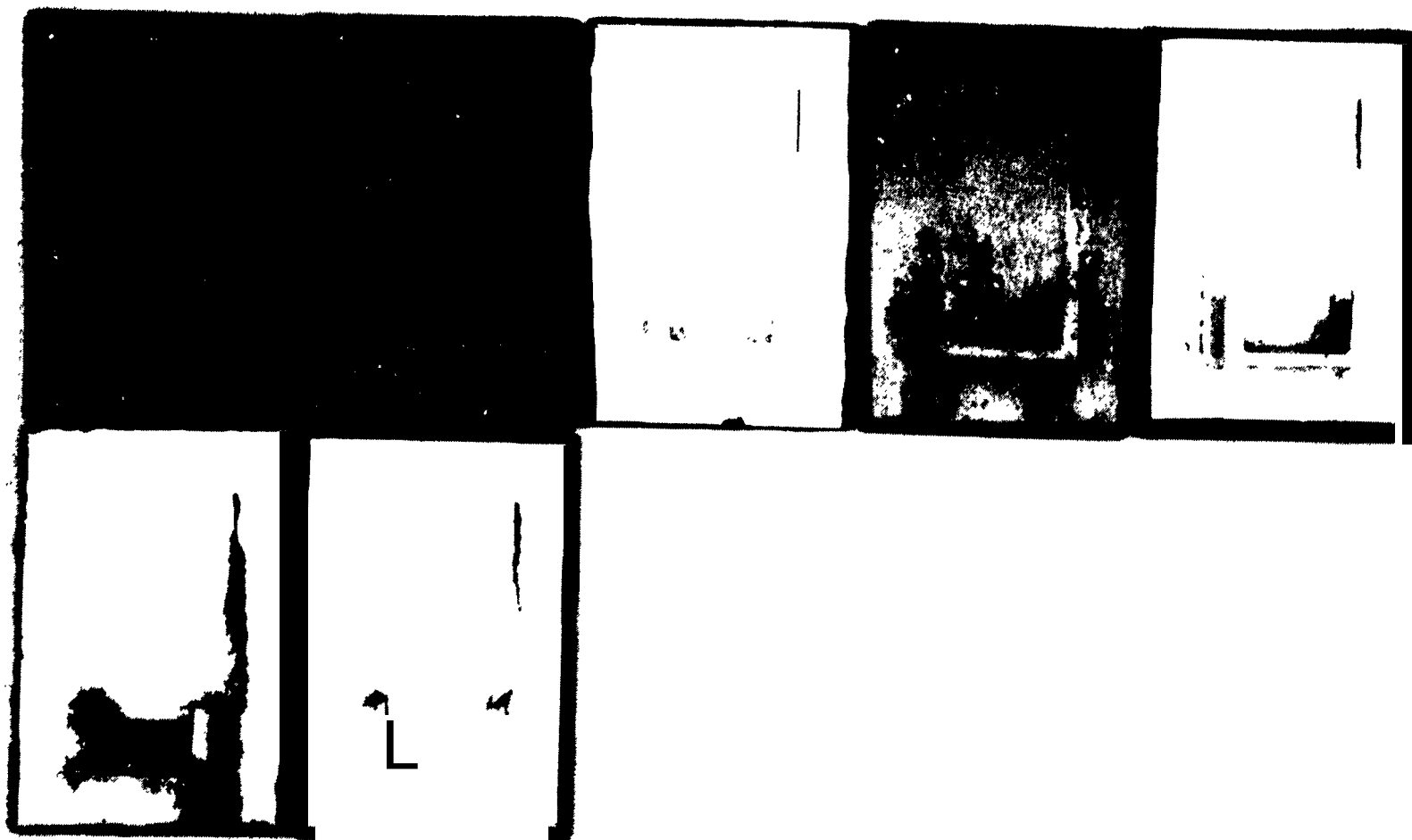
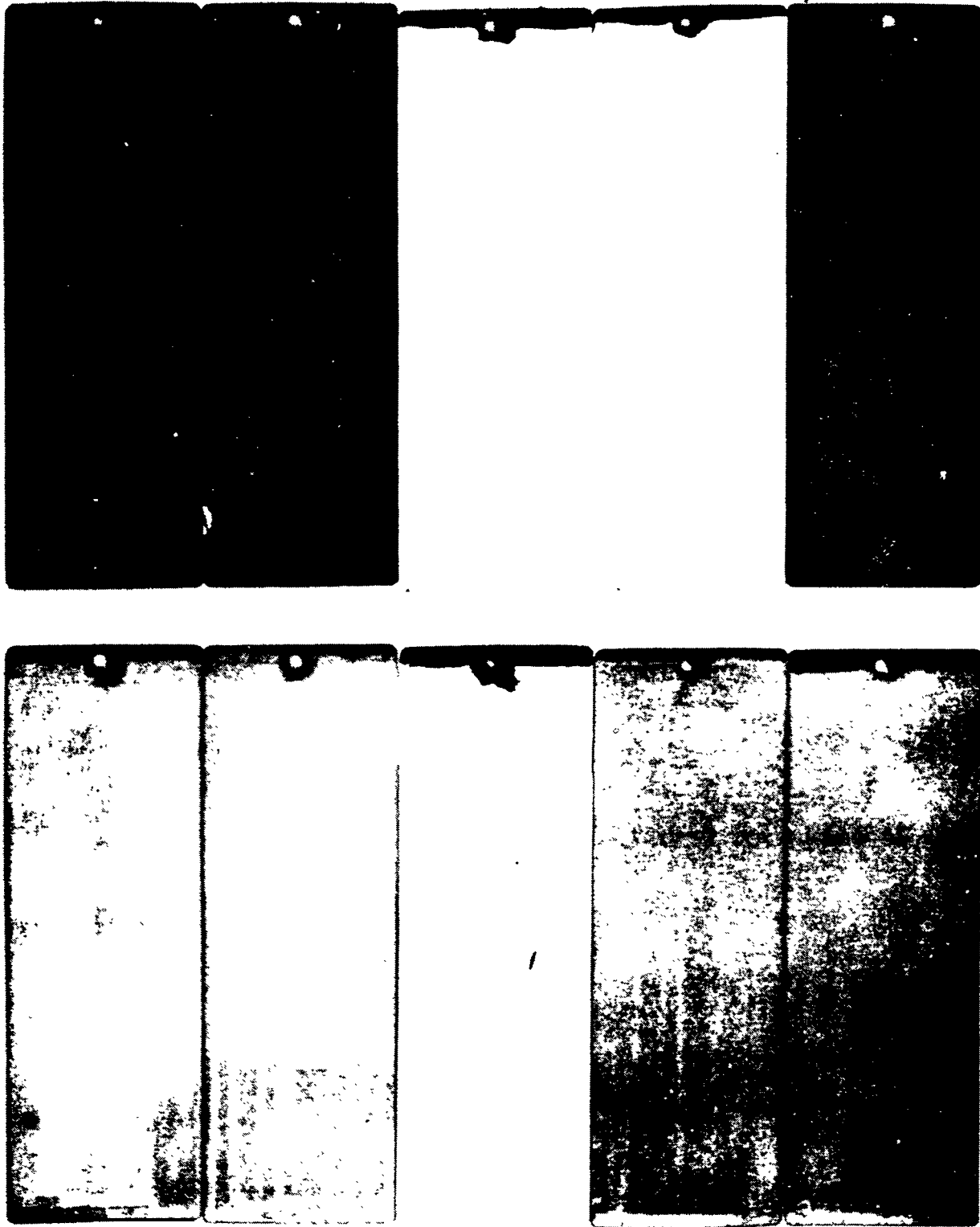


FIGURE 2.11: Inorganic Zinc, Chlorinated Rubber Paint Systems from Various Suppliers After 2000 Hours in Synthetic Sea Water-Salt Spray Cabinet



**FIGURE 2.12: Two Different Supplier's Inorganic Zinc Plus Various Topcoats
Paint Systems After 1000 Hours in Weatherometer**

SECTION 3

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ANNEX A
Letter to Shipbuilder with
Questionnaire



Offshore Power Systems

August 1, 1977

Dear Sir:

Although no figures are immediately available on the exact dollars expended annually by the marine industry on paints and coatings operations, it is known that in FY1974, over \$.750 million was spent on MarAd subsidized shipbuilding contracts. It is also a generally accepted fact that approximately 10 percent of shipbuilding costs are consumed in initial ship painting. Other industries spend from one to two percent on painting. This means that the marine industry is probably spending upwards of five times more on painting than it should.

In 1970, the National Shipbuilding Research Program was chartered by the Merchant Marine Act of that same year. The objective of that program is the reduction of shipbuilding costs through improved technology to make American shipyards more competitive on the world market.

One of the prime areas of the National Shipbuilding Research Program is Paints and Coatings Research and Development. Accordingly, the following two (2) projects were approved by MarAd for study:

A. Practical Shipbuilding Standards for Surface Preparation and Coatings

B. Marine Coatings Performance for Different Ship Areas.

The first step toward accomplishment of the objectives of these R & D projects is to solicit pertinent information from the various facets of the Marine Industry. Two questionnaires are attached for this purpose. The first questionnaire attempts to determine Paints and Coatings constraints imposed by (1) normal shipbuilding practices, (2) shipbuilding coatings application methodology and,

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(3) environmental factors due to geographical location. The second questionnaire requests information on service histories.

A requisite part of these studies is the input of information from the various shipbuilding companies. Your company's participation together with that of additional companies being contacted will provide a forum in which problems and experience can be shared. The solutions being developed in this program will increase the productivity of the industry. Please have someone in your organization complete the enclosed questionnaires and submit them to the undersigned at your earliest convenience.

Completed questionnaires will be compiled and incorporated into a computer evaluation program. A copy of this evaluation will be sent to each participating shipyard. Furnished data will be used on a cumulative basis with specific information used only as agreed upon.

The success and usefulness of these projects are dependent upon the degree of participation by each shipyard. This is a MarAd Project for the Marine Industry, our Industry. Please help.

Respectfully yours,

Benjamin S. Fultz
Project Manager
Paints and Coatings

SHIPYARD PAINTING/COATING CONSTRAINTS - STANDARDOS QUESTIONNAIRE

Recapitulation of all Response

1. Name and Address of Participating Activity:

Instructions: Unless otherwise noted, a (✓) or (X) should be placed in the appropriate block.

2. Shipyard environment conditions: (State) _____

H ☐ Hot Dry, Cold, Wet, Humid, etc.)

3. Shipyard geographical location: (a) N.E. Atlantic _____

(b) Mid Atlantic 2 _____

(c) S.E. (Atlantic) _____

(d) Gulf 5 _____

(e) N.W. (Pacific) 3 _____

(f) S.W. (Pacific) 2 _____

(g) Inland Waterways 3 _____

(h) Great Lakes 1 _____

4. In your steel cycle, at what stage of fabrication is steel cleaned and primed?

	<u>YES</u>	<u>NO</u>	PART	N/A
(a) Purchase preprimed steel plates/shapes	<u>2</u>	<u>9</u>	2	
(b) Clean and prime all steel plates/shapes prior to storage	2	11	1	
(c) Clean and prime all steel plates/shapes immediately prior to fabrication	6	5	<u>5</u>	<u> </u>
(d) Clean and prime steel weldments after fabrication but prior to erection	8	3	8	1
(e) Clean and prime after erection	7	3	5	<u> </u>

5. If you use a prefabrication primer, why?

(a) Steel Corrosion Protection	<u>10</u>
(b) Provides Cleaner Working Environment	<u>8</u>
(c) Contract Requirements	<u>6</u>
(d) Color Code	<u>3</u>
(e) Other (State) _____	

6. Do you remove prefabrication- primer after fabrication and reprime prior-to erection?

1 YES 7 NO 5 PART 4 N/A

7. Do you remove prefabrication primer after fabrication and erection but prior to final paint/coating application?

1 YES 9 NO 4 PART 3 N/A

8. Initial surface preparation:

YES NO ABRASIVE TYPE/SIZE(State)

(a) Automatic Abrasive Blasting

6 S-50, S-390, S-460

(b) Manual Abrasive Blasting

4 G-40, S-330, S-280

(c) Automatic Power Tool Cleaning

1 9 G-230. J-50

(d) Manual Power Tool Cleaning

5 6

(e) Chemical Cleaning

9

(f) Other (State) Broom Cleaning to Remove Construction Debris Only

9. Touch Up Surface Preparation Prior to Final Paint/Coatings Application:

(a) Automatic Abrasive Blasting

1 11

(b) Manual Abrasive Blasting .

17 2 Mineral Grit, Sand,

(c) Manual Power Tool Cleaning

15 2 Coal Slag, 20-40 Mesh.

(d) Hand Tool Cleaning

11 2 Ottawa Silica, Glass

(e) Chemical Cleaning

2 8 Shot

(f) Other (State) _____

10. Do you "weld thru" Primers

YES NO YES, BUT AT REDUCED RATE

(a) Manual Stick

11 6 2

(b) SAW

4 13 2

(c) SMAW

5 13 1

(d) GMAW - Solid Wire

3 13 2

(e) GMAW - Cored Wire

4 14 1

(f) Other (State) FAB

2 0 0

11. Type (s) of primer used?

(a) Epoxy 10

(b) Alkyd 7

(c) Inorganic Zinc 15

(d) Organic Zinc 2

(e) Wash Primer 9

(f) Epanol/Phenoxy 1

(g) One Component Epoxy 4

(h) Epoxy Ester 3

(i) Other(State)

12. How long will primer last prior to requiring extensive repair?

(a) Three (3) Months 6

(d) Eighteen (18) Months 2

(b) Six (6) Months 4

(e) Twenty-four (24) Months 4

(c) Twelve (12) Months 4

(f) Other(State)

13. What is the major cause of primer failure?

(a) Shipyard Construction Damage 11

(b) Paint/Coatings Failure 3

(c) Other (State) Surface Prep., Environment

14. What is the percentage of primer repair prior to finish painting?

1% 1 4 4 1 2 2 1
5% 10% 20% 25% 40% 50% 60% 75% 90% 100%

15. What is the most desired attribute of a primer and why?

Maintain Clean Work Environment, Corrosion Prevention, Weld thru

all welding processes to radiography standard, Topcoat Compatibility,

Ease of Application, Fast Dry

16. What is the percentage of preoutfitting prior to module/assembly erection?

0-85%

17. What is the percentage of finish painting accomplished prior to module/assembly erection?

0-90%

18. What is the percentage of total outfitting accomplished prior to launch?

40-100%

19. What is the percentage of finish painting accomplished prior to launch? 15-95%
20. Of the finish painting accomplished prior to erection and/or launch, what is the percentage of repair prior to delivery. 5-40%
21. List in order of importance, the following constraints which impose difficulty on painting/coatings operations. Begin with number 1 as being the most restrictive.
- | | | | |
|---|-----------------------|-----------------------------------|-----------------------------|
| (a) Weather/Environment | <u>2.17 (Average)</u> | (e) Quality Assurance/ | <u>5.11 (Average)</u> |
| (b) Production Interferences | <u>2.17 (Average)</u> | (f) Paint/Coatings Specifications | <u>4.24 (Average)</u> |
| (c) Planning | <u>3.56 (Average)</u> | (g) Inadequacies of Drawings | <u>6.53 (Average)</u> |
| (d) Difficulty of Paint Materials Application | <u>3.59 (Average)</u> | (h) Other (State) | <u> </u> |
22. In the following categories of constraints which specific Problems cause interference with painting/coatings application for. your company?

	YES	NO
A. Weather: 1 High Humidity	<u>15</u>	<u>4</u>
(2) Low Humidity	<u> </u>	<u>18</u>
(3) High Temperature	<u> </u>	<u>12</u>
4 Low Temperature	<u> </u>	<u>-</u>
(5) Sudden Rain Showers	<u>16</u>	<u>3</u>
(6) Long Periods of Rainy Weather	<u>10</u>	<u>9</u>
(7) Other(State) <u>Snow, Ice</u>	<u> </u>	<u> </u>

B. Production Interferences:

(1) Interference from Other Crafts	<u>18</u>	<u> </u>
(2) Lack of Required Tools/Equip	<u>1'</u>	<u> </u>
(3) Lack of Skilled/Trained Craftsman	<u>8</u>	<u> </u>
(4) Lack of Accessibility to Job	<u>9</u>	<u> </u>
(5) Poor Ventilation	<u>17</u>	<u>7</u>
(6) Poor Lightin	<u>16</u>	<u>0</u>
(7) Other (State) <u> </u>	<u> </u>	<u> </u>

C. Planning:

(1) Interference from other Crafts	<u>17</u>	<u>2</u>
(2) No Planned Paint/Coating Activities	<u>8</u>	<u>11</u>
(3) Work released for finish paint prior to compartment completion	<u>16</u>	<u>2</u>
(4) written process instruction not available to paint..craft personnel;	<u>3</u>	<u>16</u>

C. Planning. (con't)

5. Other (State)

D. Paint/Coatings Materials:

	YES	NO
(1) Short Pot Life	<u>12</u>	<u>7</u>
(2) Slow Cure/Dry	<u>12</u>	<u>7</u>
(3) Unpleasant Odor	<u>7</u>	<u>12</u>
(4) Low Flashpoint	<u>7</u>	<u>12</u>
(5) Minimum Recoat Time Too Long	<u>12</u>	<u>7</u>
(6) Maximum Recoat Time Too Short	<u>5</u>	<u>14</u>
(7) Lack of Application Instructions	<u>7</u>	<u>17</u>
(8) Application Method Too Complicated for average craftsman	<u>2</u>	<u>17</u>
(9) Surface Prep cannot be accomplished	<u>4</u>	<u>15</u>
(10) Other (State)	<u> </u>	<u> </u>

E. Quality Assurance/Control

(1) written instructions with inspection attributes are not available to inspectors	<u>5</u>	<u>14</u>
(2) Inspectors are not school trained	<u>6</u>	<u>13</u>
(3) Inspection attributes are purely subjective	<u>5</u>	<u>14</u>
(4) Other (Stdte) <u>personality of</u> Inspectors		

F. Paints/Coatings Specifications:

(1) Specifications are overly restrictive	<u>5</u>	<u>14</u>
(2) Specifications contains production sequencing requirements which cannot be followed.	<u>3</u>	<u>16</u>
(3) Other (State) <u>specification</u> not compatible with shipyard methods		

G. Paint/Coatings Finishing Schedules:

(1) Incomplete Schedules	<u>4</u>	<u>15</u>
(2) Schedules/Drawings difficult to understand	<u>2</u>	<u>17</u>
(3) Other (State) <u> </u>		

H. List in order of priority five(5) major shipyard paint/coatings problems/constraints.

1. Obtaining Required Cleanliness Standards
2. Obtaining Film Thickness with Specified Number of Coats
3. Elimination of Paint Pinholes
4. Inspectors not trained
5. Specifications Too Subjective
6. Safety Problems
7. Craft Interference
8. Production/Scaffolding Damage

9. Material Application Requirements

10. Accessibility
11. Atmospheric Conditions
12. Blistering in Tanks
14. Equipment Down Time personnel
- 161 Structural Interferences

	YES	NO
23. Does the Coatings/Paint Supplier Provide direct on the job assistance to craft personnel on a routine basis?	<u>10</u>	<u>9</u>
24. QUALITY ASSURANCE/QUALITY CONTROL:		
(1) Marine surveyor Inspection	<u>14</u>	<u>5</u>
(2) Owner Inspection	<u>19</u>	<u>0</u>
(3) QA/QC Dept. Inspectors	<u>15</u>	<u>4</u>
(4) Craft Inspectors	<u>8</u>	<u>11</u>
(5) Craft Supervision Inspection Only	<u>6</u>	<u>13</u>
(6) QA/QC Dept. Audit Only	<u>2</u>	<u>17</u>
(7) Are Inspectors School Trained?	<u>4</u>	<u>15</u>
(8) Are Written Instruction Sheets Used?	<u>9</u>	<u>10</u>
(9) Other (State) _____		
25. Paints/Coatings Specifications And Standards:		
(1) Are paints/coatings specifications complete?	<u>13</u>	<u>6</u>
(2) Are paints/coatings specifications overly restrictive	<u>10</u>	<u>d</u>
(4) Are paints/coatings standards used? Are specifications available directly to craft personnel?	<u>10</u>	<u>9</u>
(5) Which of the following Standards are used?		
(a) Steel Structure Painting Council Surface Preparation Standards	<u>15</u>	<u>u</u>
(b) National Association of Corrosion Engineer (NACE) Visual Standards for Blast Cleaned Steel	<u>7</u>	<u>12</u>
(c)-NBS Certified Coating Thickness Calibration Standards	<u>9</u>	<u>10</u>
(d) Steel Structures Painting Council Paint Thickness Measurements SSPC-PA 2-73T	<u>13</u>	<u>6</u>
(e) The Society of Naval Architects and Marine Engineers Abrasive Blasting Guide for Aged or Coated Steel	<u>4</u>	<u>15</u>
(f) Japanese Standard for the Preparation of Steel Surfaces Prior to Painting	<u>1</u>	<u>18</u>
(g) Pictorial Surface Preparation Standards for painting steel surfaces	<u>9</u>	<u>10</u>
(h) ASTM D 2697-73, Volume Nonvolatile matter in Clear or Pigmented Coatings	<u>5</u>	<u>14</u>
(i) Other: (State) _____		
26. please attach any Paint/Coatings Specifications and/or Process Instructions presently being utilized in your operations.		

THANK YOU FOR YOUR COOPERATION

ANNEX B
Marine Coating Suppliers
Consolidated Questionnaire



Offshore Power Systems

June 20, 1977

Dear Sir:

The National Shipbuilding Research Program, chartered by the Merchant Marine Act of 1970, has a major objective, the reduction of shipbuilding cost, thus reducing the percentage subsidy required for American Yards to be competitive with the foreign shipbuilding industry. This objective can be accomplished by greater productivity created by new and improved technology.

The Ship Production Committee of the Society of Naval Architects and Marine Engineers was selected as the evaluation and selection organization for proposed Maritime Research and Development Projects to accomplish the objectives of the 1970 Act. In accordance with this functional responsibility, the Ship Production Committee of SNAME recommended that the following two (2) projects for study during 1977 and early 1978:

- A. Practical Shipbuilding Standards for Surface Preparation and Coatings
- B. Marine Coatings Performance for Different Ship Areas.

Offshore Power Systems was selected to perform these two (2) studies.

The first step toward accomplishment of the objectives of these R&D projects is to poll the various facets of the Marine Industry. Your company, as a recognized leader in the Marine Coatings field, was selected to participate on a voluntary basis. Two (2) questionnaires are attached for this purpose. Please have someone in your organization fill out these questionnaires and return them to the undersigned at your earliest convenience.

Coatings Suppliers
June 20, 1977
Page 2

The first questionnaire attempts to determine coatings suppliers interpretation of coatings criteria and generic recommendations for different geographical locations of application and ship area coated, and to determine formulation constraints imposed by raw material properties, availability and cost. The second questionnaire requests information on service histories.

Completed questionnaires will be compiled and incorporated into a computer evaluation program. A copy of this evaluation will be sent to each participant. Furnished data will be used on a cumulative basis with specific information used only as agreed upon.

The success, failure or usefulness of these projects is dependent upon the amount of participation by each respondent. This is a MarAd Project for the Marine Industry, OUR Industry. Please help.

Respectfully yours,

Benjamin S. Fultz
Project Manager
Paints and Coatings

BSF/nw

Enclosures

MARINE COATINGS SUPPLIERS - QUESTIONNAIRE

CONSOLIDATED LIST

1. NAME and ADDRESS of participating activity:

A. Ameron	E. Exxon	I. Mobil	M. Sigma
B. Briner	F. Imperial	J. M & T	N. Tnemec
C. Carboline	G. International	K. Napko	
D. Devoe	H. Keeler and Long	L. Porter	

2. What factors should be considered in selecting an optimum paint/coatings system?
List as many as you like in order of priority.

See Attached List

3. What, if any, formulation constraints are imposed by raw material properties?

See Attached List

4. What formulation constraints are imposed by raw material availability and/or cost?

- A. Availability of solvents meeting air pollution requirements.
- B. Toxicological restrictions
- C. Long delivery times
- D. Unavailability of some antifouling toxins such as arsenic and mercury
- E. Cost is a major factor depending on market, % solids in formula and raw material price rises.
- F. Temporary ingredient scarcity; e.g., recent zn dust shortage.
- G. Availability of resins to formulate 100% solid materials and aqueous coatings with corrosion resistance comparable to best solvent type.

5. In your option, what is the optimum number of coats of paint which should be used in a given paint system?

Three

6. List the environmental factors which should be considered when applying a paint system. Also include a method or standard for measuring a particular factor or condition.

See Attached List

7. What method or standard should be used to measure substrate cleanliness prior to painting/COatitlg? ViSual by owner **representative, Japanese SPSS - S.SPC Surface Preparation Standards, NACE Visual Standards, SNAME Standards, Swedish Pictorial Standards: white handkerchief.**

8. Should a materials qualification testing program be instituted to qualify coating systems for the following ships areas? If so, what standard should be used?

a. Underwater Bottom	7 - yes; 2- No; 5 - No comment
b. Freeboard	4 - yes; 4 - No; 6 - No comment
c. Tanks, Ballast	6 - yes; 3 - No; 5 - No comment
d. Tanks, Potable Water	4 - yes; 3 - No; 7 - No comment
e. Tanks, Clean Cargo	5 - yes; 3 - No; 6 - No comment
f. Tanks, Crude	6 - yes; 3 - No; 5 - No comment
g. Cargo Holds/Spaces	2 - yes; 5 - No; 7 - No comment
h. Engine/Machinery Spaces	2 - yes; 5 - No; 7 - No comment
i. Living Spaces	1 - yes; 6 - No; 5 - No comment

9. Should paint inspectors be qualiffed/certified to a standard? If yes, what standard/ method? **14 - yes; 0 - no; 0 - No comment - No standard presently available. So= vendors provide service; ASTM, NACE presently working on standards.**

10. Is blast profile an important factor in paint/coating system performance? If yes, what is the optimum, how can it be measured and to what standard?

Yes - Varies with vendor. Depends on dry film thickness; "optimum is 1/3 of DFT"; no standard presently exists. Keane-Tator Profile comparator; Clemco comparator; SSPC Microscopic method; Profilometer; pull off thickness gauge; select abrasive particle size.

11. How should dry film measurement be accomplished? **SSPC-PA2-Magnetic pull-off gauge; "Manufacturer" method not taking into account profile, "Tooke" gauge.**

12. How should film thickness measuring devices be calibrated and to what standard?

SSPC using NBS Standards; ASTM E-376-69

13. How should volume solids be measured and verified? What standard should be used?

Inorganic zinc - volatile measurement or wet/dry film (GSA Method) Organic Coatings

ASTM D-2697

14. What attributes should remeasured and verified during application of paints/coatings?
- | | | |
|--------------------------------|-------------------------------|--------------------------|
| A. Surface Cleanliness | F. Film Thickness (Wet & Dry) | K. Equipment Set-up |
| B. Profile | G. Dry Times between Coats | L. Quality of Air |
| C. Temperature and Humidity | H. Ventilation | M. Film Appearance |
| D. Humidity | I. Holidays (Spark Test) | N. Time before immersion |
| E. Correct Mixing and Thinning | J. Area Coated | O. Hardness |
| Weight per Gallon | Viscosity | Solvent Concentration |

15. Should painters be qualified/certified in accordance with a program similar to the welder qualification standards?

12 - Yes; 2 - No; no program available

16. If you could write a specification exactly the way you wanted to, what would be the format? Include generic types and a rationale for using each type.

17. Would your company be interested in attending a seminar at Offshore Power Systems sometime in the month of November 1977?
The purpose of the seminar will be to discuss input and goals of the program.

18. Would your company be interested in participating in a materials test program where generic products from different sources are evaluated on an equal basis?

QUESTION No. 2

A. Performance (13)

The applied generic coating system accomplishes the intended result for which it is applied, i.e.:

- (1) Corrosion protection of part, component, area, etc.
- (2) Cosmetics
- (3) Aesthetics
- (4) Increased Fuel efficiency

B. Cost (11)

Cost per square foot of applied coating system calculated over the life cycle of the vessel, includes:

- (1) Initial cost - material consumption using volume solids method, surface preparation and application cost.
- (2) Service life - Length of time between initial application and renewal of coating system.
- (3) Maintenance cost - cost incurred repairing and renewing a coating system to a state where it accomplishes the intended performance.
- (4) Increased fuel efficiency.
- (s) Increased vessel availability.
- (6) Cash flow considerations.

C. Application Conditions and Restrictions (11)

Ability to apply the specified coating system under the conditions imposed at the time of application. includes both initial application and maintenance applications. Some conditions and restrictions are:

- (1) Environmental - Temperature, humidity, and other ciimatic conditions.
- (2) Equipment availability
- (3) Application skili
- (4) Job planning to include sequence and adequate allotment of time to accomplish correct painting operations.

D. Paint Formula Design (11)

The following points should be considered when selectiing.formulating a given painticoating.

- (1) Environmental conditions under which the paint can and will be applied, i.e., realistic minimum/ maximum humidity and temperature.
- (2) Tolerance for film build both minimum and maximum.
- (3) Fiexibiitiy of cured material.
- (4) Recoat times - minimum and especially maximum.
- (5) Dry/cure requirements - minimum/maximum humidity and temperature.
- (6) Optimum number of coats of paint within a given system.
- (7) Abrasion resistance
- (8) Corrosion inhibition
- (9) Adhesion
- (10) Application properties - sprayability, brushability, amount and type reducer required, equipment required, etc.
- (11) Compatibility with preappiied, cured coatings. Includes initial system application and maintenance.
- (12) Surface preparation - Type surface preparation required, widest toierance for less than perfect. includes initial and more importantly, touch-up and repair.

E. Quaiified applicators (4)

F. Maintainabiitiy of applied system (3)

G. Availability and quality of vendor supplied, on site technical service (3).

H. Qualified Inspectors (2).

L Safety (1)

Toxicity and flammability of materials during and after application. Minimum flash points on materials designed for application in enclosed areas.

J. Availability of materials both initially and during overhauL

K. Financiai soundness of vendor (l).

QUESTION No. 3

A. Solvents

- (1) Flash Points
- (2) OSHA/EPA Emission Limits
- (3) Drying Times
- (4) Film Entrapment

B. Resins/Binders

- (1) Application properties such as viscosity, flow, sprayability, etc.
- (2) Topcoatability
- (3) Solids Content
- (4) Susceptibility to moisture, i.e., moisture vapor permeability.
- (5) Chemical resistance
- (6) Influences film build
- (7) Drying\Curing times
- (8) Inherent nature of some polymers impose stringent surface preparation requirements
- (9) O2 discoloration and degradation
- (10) OSHA/EPA exposure limits

C. Pigment

- (1) Chemical resistance properties
- (2) Colored pigment limitations for optimum weathering resistance
- (3) Influences film build
- (4) Moisture/Water sensitivity
- (5) Corrosion resistance
- (6) Inhibition properties
- (7) Cost (particularly colored top coats)
- (8) Influences film build
- (9) EPA/OSHA exposure limits

QUESTION No. 6

Environmental Factors

- A. Air Temperature
- B. Surface Temperature
- C. Material Temperature
- D. Air Velocity
- E. Relative Humidity
- F. Dew Point -2 to 5 degrees within
- G. Solvent vapor content in tanks or confined spaces
- H. Local and Federal Emission Laws
- I. Dust emitted during cleaning operations
- J. Spray dust emissions, particularly heavy metals
- K. Direct sun affecting substrate temperature
- L. SO₂ and Chloride ion content

Method or Standard

- A. Thermometer
- B. Surface Thermometer
- C. Thermometer
- D. Air Flow Meter
- E. Sling or Electric Psychrometer
- F. Sling Psychrometer
- G. —
- H. —
- I. —
- J. —
- K. —
- L. Drager Tubes

ANNEX C
Ships Paints/Coatings Performance-
Service
Histories Questionnaires

INSTRUCTIONS FOR COMPLETING SHIPS PAINTS/COATINGS - SERVICE HIISTORIES QUESTIONNAIRE

(Al so see completed example)

1. Paragraph 01 - As stated this is optional information
2. Paragraphs 02 and 03 - Self explanatory
3. Lines 041 through 049 -
 - a) Surface Preparation - See Surface Preparation Code Number
 - b) Primer and Topcoats - Select appropriate type code from Paint Types at the bottom of page, i.e. code 15 for alkyd, 32 for chlorinated rubber, etc.
 - c) Mils - List roils to the nearest tenth, i.e. 1.5, 10.0, 9.6 etc.
4. Add new column at the left of boxes 041-049. Insert life of system to the nearest tenth of a year, i.e. 0.5 for six months, 1.0 for one year, etc. This entry is one of the most important. (see example). Life of system is time since last overhaul or major maintenance period.
5. Paragraphs 0511 - 0594 - Place an X or check in the appropriate block.
6. Special Instructions - Any input will be appreciated. For example, if a survey is accomplished only on a specific area of a ship instead of the complete ship, please submit just this information. The more the information, the more valid the study becomes.
7. Mail completed questionnaires to:

Benjamin S. Fultz
Offshore Power Systems
P. O. Box 8000
Jacksonville, Florida 32211

SHIPS PAINTS/COATINGS PERFORMANCE-SERVICE HISTORIES QUESTIONNAIRE

CONTROL NUMBER

OPTIONAL INFORMATION:

OWNER

SHIPS NAME

BUILDER

02 TYPE OF SHIP (Please circle most appropriate type)

TANKER 10 / DRY CARGO 11 / FISHING 12 / OBO 13 / CONTAINER 14 / FERRY 15 /
 RO-RO 16 / REEFER 17 /

03 TRADE ROUTE (Please circle most appropriate route)

SOUTH PACIFIC 20 / WEST INDIES 21 / NORTH ATLANTIC 22 / SOUTH ATLANTIC 23 /
 NORTH PACIFIC 24 / CARIBBEAN 25 / MEDITERRANEAN 26 /

PAINT SYSTEMS UTILIZED (See table below for Code Numbers)

AREA		Surface Prep.	PRIMER			COAT #2			COAT #3			COAT #4			COAT #5			COAT #6				
			TYPE	MILS		TYPE	MILS		TYPE	MILS		TYPE	MILS		TYPE	MILS		TYPE	MILS			
041 UNDERWATER BOTTOM		1			2			3			4			5			6			7		
042	BOOTTOP	1			2			3			4			5			6			7		
043 FREEBOARD		1			2			3			4			5			6			7		
044	EXTERIOR DECKS	1			2			3			4			5			6			7		
045	EXTERIOR SUPER- STRUCTURE	1			2			3			4			5			6			7		
046	CARGO HOLDS & SPACES	1			2			3			4			5			6			7		
047 PRODUCT TANKS		1			2			3			4			5			6			7		
048	BALLAST TANKS	1			2			3			4			5			6			7		
049	MACHINERY SPACES	1			2			3			4			5			6			7		

SURFACE PREPARATION CODE NUMBERS:

10. SSPC-SP-1 12. SSPC-SP-5
 11. SSPC-SP-3 13. SSPC-SP-6 14. SSPC-SP-10

PAINT TYPES

- | | | |
|---|---------------------------|--|
| 15. Alkyd | 31. Bitumenous | 49. Polystyrene |
| 16. Alkyd, Silicone | 32. Chlorinated Rubber | 50. Polyurethane |
| 17. Alkyd, Modified Acrylic | 33. Emulsion Latex | 51. Polyvinyl Chloride Copolymer |
| 18. Alkyd, Vinyl | 34. Epanol, Phenoxy | 52. Powder |
| 19. Antifouling, Coal Tar Epoxy, | 35. Epoxy, Adduct | 53. Varnish |
| 20. Organometallic | 36. Epoxy, Coal Tar | 54. Vinyl |
| 21. Antifouling, Chlorinated Rubber, Copper | 37. Epoxy, Ester | 55. Vinyl Alkyd |
| 22. Antifouling, Chlorinated Rubber, Organometallic | 38. Epoxy, Ketamine | 56. Wash Primer |
| 23. Antifouling, Epoxy, Copper | 39. Epoxy, One Component | 57. Water Borne, Epoxy |
| 24. Antifouling, Epoxy, Organometallic | 40. Epoxy, Phenolic | 58. Water Borne, Enamel |
| 25. Antifouling, Hot Plastic, Copper | 41. Epoxy, Polyamide | 59. Zinc, Galvanized |
| 26. Antifouling, Rubber Sheet, Organometallic | 42. Epoxy, Polyamine | 60. Zinc, Inorganic, Post Cure |
| 27. metallic | 43. Epoxy, Polyester | 61. Zinc, Inorganic, Self Cure Solvent Based |
| 28. Antifouling, Vinyl, Copper | 44. Epoxy, Other | 62. Zinc, Inorganic, Self Cure Water Based |
| 29. Antifouling, Vinyl Organometallic | 45. Lacquer | 63. Zinc, Inorganic, with conductive Extenders |
| 30. Antifouling, Other | 46. Metal Spray, Aluminum | 64. Zinc, Inorganic, Other |
| | 47. Metal Spray, Zinc | 65. Zinc, Organic |
| | 48. Polyester | 66. Oth&s " |

(Over)

PERFORMANCE EVALUATION

Please Mark Appropriate Box(s) ☒

UNDERWATER BOTTOM:

- 0511 (a) % Fouling
0512 (b) % Corrosion
0513 (c) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0514 (d) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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- 0515 (e) Type Fouling

☐ Grass	☐ 1	☐ Shell	☐ 2	☐ Slime	☐ 3	☐ Comb.	☐ 4
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BOOTTOP:

- 0521 (a) % Fouling
0522 (b) % Corrosion
0523 (c) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0524 (d) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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- 0525 (e) Type Fouling

☐ Grass	☐ 1	☐ Shell	☐ 2	☐ Slime	☐ 3	☐ Comb.	☐ 4
--------------------------------	----------------------------	--------------------------------	----------------------------	--------------------------------	----------------------------	--------------------------------	----------------------------

FREEBOARD:

- 0532 (a) % Corrosion
0533 (b) % Coating Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0534 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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EXTERIOR DECKS:

- 0542 (a) % Corrosion
0543 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0544 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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EXTERIOR SUPERSTRUCTURE

- 0552 (a) % Corrosion
0553 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0554 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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CARGO HOLDS & SPACES

- 0562 (a) % Corrosion
0563 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0564 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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PRODUCT TANKS

- 0572 (a) % Corrosion
0573 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0574 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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BALLAST TANKS

- 0582 (a) % Corrosion
0583 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0584 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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MACHINERY SPACES

- 0592 (a) % Corrosion
0593 (b) % Coatings Failure

0%	1%	5%	10%	15%	25%	50%	75%	90%	100%
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

- 0594 (c) General Appearance

☐ Unsat.	☐ 1	☐ Poor	☐ 2	☐ Fair	☐ 3	☐ Good	☐ 4	☐ Excellent	☐ 5
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Example

leave blank

SHIPS PAINTS/COATINGS PERFORMANCE—SERVICE HISTORIES QUESTIONNAIRE

CONTROL NUMBER

0 1 OPTIONAL INFORMATION:

ABC Ship Co

OWNER

Fair Lady

SHIPS NAME

XYZ Shipyard

BUILDER

0 2 TYPE OF SHIP (Please circle most appropriate type)

TANKER 1 0 / DRY CARGO 1 1 / FISHING 1 2 / OBO 1 3 / CONTAINER 1 4 / FERRY 1 5 /
RO-RO 1 6 / REEFER 1 7 /

0 3 TRADE ROUTE (Please circle most appropriate route)

SOUTH PACIFIC 2 0 / WEST INDIES 2 1 / NORTH ATLANTIC 2 2 / SOUTH ATLANTIC 2 3 /
NORTH PACIFIC 2 4 / CARIBBEAN 2 5 / MEDITERRANEAN 2 6 /

PAINT SYSTEMS UTILIZED (See table below for Code Numbers)

Age	AREA	Surface Prep.	PRIMER		COAT #2		COAT #3		COAT #4		COAT #5		COAT #6	
			TYPE	MILS	TYPE	MILS	TYPE	MILS	TYPE	MILS	TYPE	MILS	TYPE	MILS
1.0	041 UNDERWATER BOTTOM	1	1 3	2 3 4 1 5	3 3 1 2 0	4 3 1 2 0	5 3 1 2 0	6 2 8 2 0	7					
2.0	042 BOOTTOP	1	1 4	2 6 0 3 0	3 4 2 4 0	4 4 1 2 0	5 1 6 1 5	6						
2.0	043 FREEBOARD	1	1 4	2 6 0 3 0	3 4 2 4 0	4 4 1 2 0	5 1 6 1 5	6						
1.0	044 EXTERIOR DECKS	1	1 4	2 6 0 3 0	3 4 2 4 0	4 4 1 2 0	5							
2.0	045 EXTERIOR SUPER-STRUCTURE	1	1 4	2 6 0 3 0	3 4 2 4 0	4 1 6 1 5	5							
2.0	046 CARGO HOLDS & SPACES	1	1 3	2 3 4 1 5	3 4 2 4 0	4								
2.0	047 PRODUCT TANKS	1	1 2	2 3 4 1 5	3 8 4 0	4 3 8 4 0	5							
2.0	048 BALLAST TANKS	1	1 4	2 3 4 1 5	3 8 4 0	4 3 8 4 0	5				6		7	
2.0	049 MACHINERY SPACES	1	1 3	2 3 4 1 5	3 1 5 2 0	4 1 5 2 0	5				6		7	

SURFACE PREPARATION CODE NUMBERS:

10. SSPC—SP—1 12. SSPC—SP—5
11. SSPC—SP—3 13. SSPC—SP—6 14. SSPC—SP—10

PAINT TYPES

- | | | |
|---|--|---|
| <ul style="list-style-type: none"> 15. Alkyd 16. Alkyd, Silicone 17. Alkyd, Modified Acrylic 18. Alkyd, Vinyl 19. Antifouling, Coal Tar Epoxy, 20. Organometallic 21. Antifouling, Chlorinated Rubber, Copper 22. Antifouling, Chlorinated Rubber, Organometallic 23. Antifouling, Epoxy, Copper 24. Antifouling, Epoxy, Organometallic 25. Antifouling, Hot Plastic, Copper 26. Antifouling, Rubber Sheet, Organometallic 27. Antifouling, Other 28. Antifouling, Vinyl, Copper 29. Antifouling, Vinyl Organometallic 30. Antifouling, Other | <ul style="list-style-type: none"> 31. Bitumenous 32. Chlorinated Rubber 33. Emulsion Latex 34. Epanol, Phenoxyl 35. Epoxy, Adduct 36. Epoxy, Coal Tar 37. Epoxy, Ester 38. Epoxy, Ketamine 39. Epoxy, One Component 40. Epoxy, Phenolic 41. Epoxy, Polyamide 42. Epoxy, Polyamine 43. Epoxy, Polyester 44. Epoxy, Other 45. Lacquer 46. Metal Spray, Aluminum 47. Metal Spray, Zinc 48. Polyester | <ul style="list-style-type: none"> 49. Polystyrene 50. Polyurethane 51. Polyvinyl Chloride Copolymer 52. Powder 53. Varnish 54. Vinyl 55. Vinyl Alkyd 56. Wash Primer 57. Water Borne, Epoxy 58. Water Borne, Enamel 59. Zinc, Galvanized 60. Zinc, Inorganic, Post Cure 61. Zinc, Inorganic, Self Cure Solvent Based 62. Zinc, Inorganic, Self Cure Water Based 63. Zinc, Inorganic, with conductive Extenders 64. Zinc, Inorganic, Other 65. Zinc, Organic 66. Others |
|---|--|---|

C-2 (Over)

PERFORMANCE EVALUATION

Please Mark Appropriate Box(s) ☒

UNDERWATER BOTTOM:

	0%	1%	5%	10%	15%	25%	50??	75%	90%	100%
0511 (a) % Fouling	0	1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0512 (b) % Corrosion	0	1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0513 (c) % Coatings Failure	0	1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0514 (d) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☒ Good 4 ☐ Excellent 5

0515 (e) Type Fouling ☐ Grass 1 ☒ Shell 2 ☐ Slime 3 ☐ Comb. 4

BOOTTOP:

0521 (a) % Fouling	☐ 0	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0522 (b) % Corrosion	☐ 0	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0523 (c) % Coatings Failure	☐ 0	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0524 (d) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☒ Fair 3 ☐ Good 4 ☐ Excellent 5

0525 (e) Type Fouling ☒ Grass 1 ☐ Shell 2 ☐ Slime 3 ☐ Comb. 4

FREEBOARD:

0532 (a) % Corrosion	☐ 0	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0533 (b) % Coating Failure	☐ 0	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0534 (c) General Appearance ☐ Unsat. 1 ☒ Poor 2 ☐ Fair 3 ☐ Good 4 ☐ Excellent 5

EXTERIOR DECKS:

0542 (a) % Corrosion	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☒ 5	☐ 6	☐ 7	☐ 8	☐ 9
0543 (b) % Coatings Failure	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☒ 5	☐ 6	☐ 7	☐ 8	☐ 9

0544 (c) General Appearance ☐ Unsat. 1 ☒ Poor 2 ☐ Fair 3 ☐ Good 4 ☐ Excellent 5

EXTERIOR SUPERSTRUCTURE

0552 (a) % Corrosion	☒ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0553 (b) % Coatings Failure	☒ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0554 (c) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☐ Good 4 ☒ Excellent 5

CARGO HOLDS & SPACES

0562 (a) % Corrosion	☒ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0563 (b) % Coatings Failure	☐ 0	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0564 (c) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☐ Good 4 ☒ Excellent 5

PRODUCT TANKS

0572 (a) % Corrosion	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☒ 6	☐ 7	☐ 8	☐ 9
0573 (b) % Coatings Failure	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☒ 6	☐ 7	☐ 8	☐ 9

0574 (c) General Appearance ☒ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☐ Good 4 ☐ Excellent 5

BALLAST TANKS

0582 (a) % Corrosion	☒ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0583 (b) % Coatings Failure	☒ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0584 (c) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☐ Good 4 ☒ Excellent 5

MACHINERY SPACES

0592 (a) % Corrosion	☐ 0	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9
0593 (b) % Coatings Failure	☐ 0	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9

0594 (c) General Appearance ☐ Unsat. 1 ☐ Poor 2 ☐ Fair 3 ☒ Good 4 ☐ Excellent 5