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SSC-390

CORROSION CONTROL OF INTER-HULL SPACES

SHIP STRUCTURE COMMITTEE

1996

SHIP STRUCTURE COMMITTEE

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SR-1366

26 April 1996

CORROSION CONTROL OF INTER-HULL SPACES

The advent of double hull vessels provides a new era of spill resistant tankers. However, with this new increased protection comes the problem of maintaining the closed-in double-bottom spaces. This study, focused primarily on merchant vessels, follows a worldwide survey of commercial shippers and shipyards for the U.S. Navy. The results conclude that the use of readily available coating systems, but with increased emphasis on quality of surface preparation and personnel training, will yield impressive results. If these practices are put in place, the North American shipping companies can achieve dramatic savings in recoating of tanks, structural repairs, and the requisite repair laydays.

J. C. Card

J. C. CARD
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

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16. Abstract

This report expands upon the work conducted by the U.S. Navy to develop a tank preservation protocol with a service life of 15 to 20 years. This report focuses on controlling corrosion in the region between the inner and outer hulls in new double hull designs. This area is treated as either a void or a seawater ballast tank. The Oil Pollution Act of 1990 has precipitated increased interest by ship owners, ship builders, ship operators, and classification societies to analyze and evaluate the long term corrosion protection requirements of the inter-hull space of double hull designs. A recommended inter-hull space preservation protocol is provided which is based upon information gathered from classification societies; U.S., European, and Japanese shipyards; coating manufacturers; maritime magazine articles; reports; and the U.S. Navy. Conclusions are provided concerning the use of cathodic protection, vapor phase inhibitors, and metal spray coatings. Guides were developed to evaluate whether to repair or replace the coating of inter-hull spaces; inspection of the coating of inter-hull spaces; quality assurance requirements for application of coatings to steel surfaces of inter-hull areas; and training of journeyman painters, painting supervisors, and paint inspectors for double hull ships.

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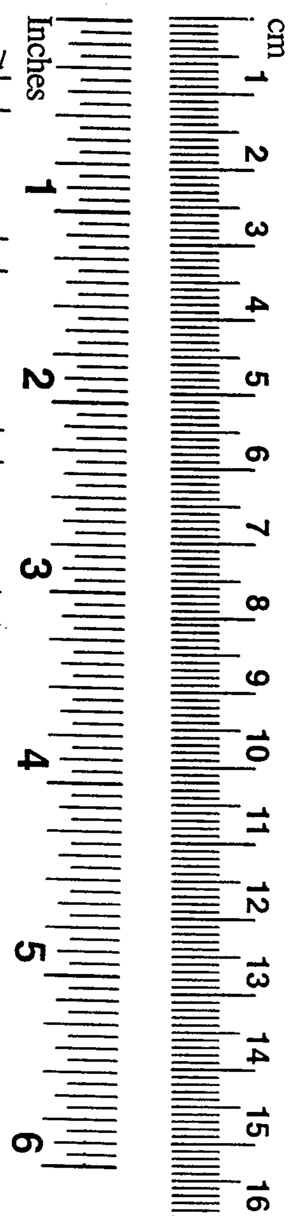
METRIC CONVERSION CARD

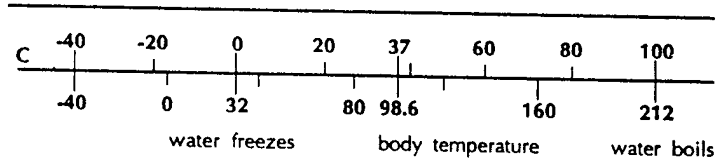
Approximate Conversions to Metric Measures

Symbol	*When You Know*	*Multiply by*	*To Find*	*Symbol*
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	subtract 32, multiply by 5/9	degrees Celsius	°C



Approximate Conversions from Metric Measures

Symbol	*When You Know*	*Multiply by*	*To Find*	*Symbol*
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares ($10{,}000\ m^2$)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1,000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	degrees Celsius	multiply by 9/5, add 32	degrees Fahrenheit	°F



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The research was conducted by the Arlington, VA office of M. Rosenblatt & Son, Inc. The project is entitled SR-1366, Corrosion Control of Inter-Hull Spaces. The objective of the project is to provide guides and standards to the marine industry that will lead to fewer failures of ship inter-hull spaces due to long term corrosion. This project is intended to expand upon the Engineering for Reduced Maintenance (ERM) tank preservation initiative conducted by the Naval Sea Systems Command (NAVSEA) Materials Engineering Group (03M).

EXECUTIVE SUMMARY

This report expands upon the work conducted by the Naval Sea Systems Command to develop a tank preservation protocol which is intended to achieve a service life of 15 to 20 years. This report focuses on controlling corrosion in the region between the inner and outer hulls in new double hull designs. This area is treated as either a void or a seawater ballast tank. With the passage of the United States Oil Pollution Act (OPA) in 1990, all new tankers trading in the U.S. are required to be of a double hull design effective January 1, 1994. The OPA has precipitated increased interest by ship owners, ship builders, ship operators, and classification societies to analyze and evaluate the long term corrosion protection requirements of the inter-hull space of double hull designs.

To produce this report, information was obtained from classification societies; U.S., European, and Japanese shipyards; coating manufacturers; maritime magazine articles; reports; and the U.S. Navy to determine the current maintenance and repair practices for inter-hull spaces. This information was assimilated and organized into a recommended inter-hull space preservation protocol. The protocol unified individual "good painting practice" inputs from the various references into a process which is expected to provide 20 years of corrosion protection to the inter-hull space. The essential elements of the inter-hull preservation protocol are:

• Radius to 3 mm all edges, drain holes, coaming, hand holds, foot holds, ladders, etc.;

• Smooth welds and remove weld spatter;

• Reduce soluble salts on the substrate to less than 3 $\mu g/cm^2$;

• Maintain a relative humidity of 50% or less during the surface preparation and coating application processes;

• Apply two coats of a light colored, high build, high solids epoxy coating system;

• Apply stripe coats to areas not accessible to the paint spray gun and to coating failure susceptible areas such as edges, weld seams, pipe hangers, foot holds, etc. after the first full coat and prior to the topcoat.

The conclusions reached from this investigation include:

• The preservation of the inter-hull space is a major concern for all participants, including ship owners, classification societies, coating manufacturers, and shipyards.

• The material condition of the inter-hull space and "consequence analysis" determine which preservation protocol is "most suitable".

- The best corrosion protection system for the inter-hull area combines a sacrificial cathodic protection system with a hard barrier coating system.

- A cathodic protection system can be designed for the inter-hull area in such a way that it is compatible with a coating system.

- A coating preservation protocol for the inter-hull area is provided which is expected to provide a 15 to 20 year service life.

- Metal spray coating systems are not practical for corrosion protection of the inter-hull area due to poor production rates, high cost, specialized equipment, and increased operator training requirements.

- Vapor phase inhibitors are not recommended for the inter-hull area due to the incompatibility of the inhibitors when the inter-hull space is used as a ballast tank.

- The steel substrate of the inter-hull area should be tested to determine the level of chloride contamination. The Bresle Test Kit with an electronic conductivity meter can quickly provide measurements of the chloride contamination of the steel substrate.

- No single tool can perform all edge rounding/radiusing in the inter-hull space. Seven inch or nine inch disc sanders or grinders with 24 grit aluminum oxide abrasive pads are best for straight runs. Smaller high speed die grinders with various attachments (i.e., flame shaped carbide burrs, concave radius deburring head, or conical stone tips) are best for hard to reach areas. Mastics, polysulfides, and an epoxy coating system specifically formulated for edge covering capacity show initial promise as edge protection systems.

- Sensors which measure the change of the substrate's electrical resistivity are recommended for the inter-hull space. Hard wired and wireless systems designed for other uses can be adapted to the inter-hull space.

Guides have been developed to:

- Evaluate whether to repair or replace the coating of inter-hull spaces;
- Inspect the coating system of inter-hull spaces;
- Provide quality assurance requirements for application of coatings to steel surfaces of inter-hull areas;
- Train journeyman painters, painting supervisors, and paint inspectors for double hull ships.

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CHAPTER 1

INTRODUCTION AND SCOPE

New double hull designs will undoubtedly present new problems to the marine industry. This research is funded by the Ship Structure Committee (SSC) and is intended to moderate one of these potential problems before it begins to manifest itself in the next generation of vessels. This project is intended to provide guidelines and standards to the marine industry that will lead to fewer failures of ship hulls from long term corrosion in the inter-hull area. For a double hull Very Large Crude Carrier (VLCC), the double hull spaces can be used as dedicated seawater ballast tanks and the surface area impacted is significant. In a typical double hull design VLCC, the water ballast tank area is now typically 240,000 to 280,000 m^2 per ship, an increase of 65 to 75% over typical single hull designs. This work is intended to expand upon the investigation conducted by the Naval Sea Systems Command. Guidelines and standards for the maintenance and repair of inter-hull spaces, inspection of inter-hull spaces, training, and quality assurance of the paint preservation process were developed. The specific tasks outlined by the SSC include:

1. Review Practices:

Review current commercial ship maintenance and repair practices within the context of established coating system repair and/or replacement criterion in inter-hull spaces.

2. Develop Recommendations:

a. Develop preservation and maintenance recommendations for use by ship owners and operators to determine the requirements for repair versus refurbishment of the coating system. Include cost comparison for repair versus refurbishment for varying degrees of coating system failure.

b. Develop inspection recommendations for use by ship owners and operators to utilize in their periodic inspection of inter-hull spaces. The inspection recommendations will include factors such as frequency, scope, degrees of coating system failure, causes of coating system failure, and inter-hull space inspection sheet.

c. Develop training recommendations which encompass all personnel who are involved in the preservation of inter-hulled spaces. The training recommendations should identify who should be trained, the training requirements for each individual, the frequency of re-training, the qualification requirements of the instructors, and instructor re-certification requirements.

d. Develop quality assurance recommendations which when followed will provide added confidence in the proper application of the coating system and a projected service life of 15 to 20 years. This standard should identify who will perform the inspection, when the inspections shall be conducted, how frequently the inspections shall be conducted, a recommended quality assurance check off sheet which includes quality assurance check points during the coating application process, and recommendations for resolving each attribute which does not pass the quality assurance check.

The review of current ship maintenance and repair practices such as vapor phase corrosion inhibitors, spray metal coatings, and edge protection systems are summarized in Chapters 4, 5, and 9, respectively.

The proposed preservation protocol for inter-hull spaces is described in detail in Chapter 6. A design methodology for a cathodic protection system for the inter-hull space is provided in Chapter 7. A recommended procedure for detecting surface contamination is described in Chapter 8. Chapter 10 provides recommended types of sensors for possible use in the inter-hull space.

CHAPTER 2

BACKGROUND

This study required that extensive information be gathered from a multitude of sources. Information was obtained from several U.S. private shipyards, European shipyards, Japanese shipyards, paint manufacturers, articles, reports, classification societies, and the U.S. Navy. After reviewing the data and comparing the various methodologies for preservation of tanks and voids (similar in configuration to inter-hull spaces), it was concluded that definitive actions to combat corrosion in these spaces have been taken by numerous maritime organizations in the international shipbuilding community.

The primary catalyst for providing enhanced corrosion protection of double hull spaces resulted from the environmental disaster of the *Exxon Valdez* and the subsequent issuance of the U.S. Oil Pollution Act (OPA) of 1990. In essence, the OPA requires all new tankers operating within the 200-mile U.S. Exclusive Economic Zone to be of a double hull design as of January 1, 1994. This directly impacts the cost to paint all of these compartments, forces shipbuilders to reassess their erection schedules to account for the considerable increase in coating work, and drives ship designers to design for easier and safer access to these compartments for increased survey work and maintenance. These double hull spaces have and will likely be used as dedicated seawater ballast tanks.

An enormous amount of research and investigation has been devoted to the preservation of double hull spaces. The comments of one ship operator summarize the conclusions of many ship operators:

"With the advent of segregated ballast tanks in tanker designs, these are now the most critical areas of the hull structure which will be prone to severe corrosion. With double hull designs with segregated ballast tanks, the long term protection of these spaces will be of vital importance, especially when shipbuilders insist upon higher tensile steels in construction. For this reason, standards for coating of water ballast tanks must be treated in the same way as those of cargo oil (product) tanks if structural integrity is ensured."[1]

"Shipbuilders must therefore recognize that the application of coating systems to all water ballast spaces, and especially in double hull tankers, should be regarded with the same importance as those applied to cargo (product) tanks where levels of quality are usually demanded by the owners."[1]

A classification society has also pointed out in their review of double hull tankers that "Corrosion is the primary factor in the deterioration of a vessel and in no location is this more true than in the ballast tanks."[2] This same classification society went on to say, "The relative difficulty of maintaining coatings in the more confined spaces of the ballast tanks and the relatively much larger surface area to be protected in the ballast tanks of a double hull tanker combined to require that much greater attention needs to be given this subject."[2]

A later report[3] by this classification society noted that the greatest number of significant corrosion problems concerned cargo/ballast tanks. The Norwegian Maritime Directorate also remarked that the single most important factor when coating new ships is the protection provided ballast tanks; for the coating system directly determines the service life of the ship.[4]

In addition to the U.S. OPA 1990 Act, two rulings in 1991 increased the importance of seawater ballast tank coatings. One rule from the International Association of Classification Societies (IACS) established a Harmonized System of Survey and Certification which promotes the importance of protective paint coatings. The condition of the coatings will be noted during tank surveys and the extent of the inspection at future annual and intermediate surveys will be dependent upon the level of protection afforded the steel structure. The condition of the coatings will be graded as either "POOR", "FAIR", or "GOOD" (See Appendix C for the definitions of IACS's ratings). If or where no coatings were applied at the time of construction, the water ballast spaces are to be inspected at annual intervals, and the coating condition is to be recorded in the Executive Hull Summary. The extent and frequency of future annual, intermediate, and special surveys will then be dependent on the protection afforded to the steel work.

The other ruling also by IACS, adopted Unified Requirement (UR) Z8 which stated that "...all salt water spaces having boundaries formed by the hull envelope should have a corrosion protection coating applied in accordance with manufacturer's requirements".[5] Though a coating system was not specified, the common interpretation of UR Z8 is to require a hard coating that has demonstrated its effectiveness and its ability to ensure a useful life of at least 10 years. In wet tanks, the coating may be combined with cathodic protection, which is then regarded as additional protection.[5]

Furthermore, in 1992, the IACS clarified the 30 month intermediate and 5 year special survey requirements and how they should be conducted. The regulations state that the surveys will be enhanced by close up examinations at hand-reach distance.[6]

The new requirement to coat water ballast tanks together with the withdrawal of corrosion control allowances is now resulting in a heightened problem recognition by ship owners and ship managers. There is much more interest in longer life products and lighter colors. Light colors are desired to easily distinguish rust and the onset of corrosion, and thus make it easier to inspect the tank. There is also an increased understanding that one-coat systems in ballast tanks are insufficient, providing justification for paying more for better systems.[6]

Coating of water ballast tanks in new double hull designs is also a major cost item for new construction ships. It is estimated that for a typical VLCC type tanker with 250,000 m^2 of water ballast tank surface area, the total shipbuilder's cost for coating these surfaces will be approximately \$5 million or 4.5% to 5.5% of the new construction cost.[6]

It is not sufficient to only have good surface preparation and an excellent coating system. In addition, the design of the ship's structure must also eliminate the presence of local stress concentrations which can result in fatigue cracking and rupture of the protective coating barrier. This is usually followed by enhanced crack propagation rates and accelerated coating failure.

Though specific cost estimates and the impact of the new IACS rules have not been quantified, there is no doubt that more surveys will be performed with a greater frequency than has ever been the case in the past. As a direct result of this, more problems in coating systems will be detected, ship owners will be required to perform more maintenance and repairs to coating systems in seawater ballast tanks, and ships will be adversely impacted operationally due to longer and/or more frequent yard upkeep periods.

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CHAPTER 3

APPROACH

The first step in determining the current commercial ship maintenance and repair practices was to research the preservation practice followed by the major participants in the ship repair business, namely shipyards, coating manufacturers, and classification societies. This effort was conducted by visits to U.S., European, and Japanese shipyards, meetings with several coating manufacturers, and a review of the rules and regulations governing the preservation of inter-hull spaces in double hull ships. Ship owners were not queried because it was assumed that the preservation practice executed by the shipyard would be the most economical procedure the ship owner would approve while still maintaining certification by the governing classification society.

Once this data was obtained, the U.S. Navy's new preservation protocol for tanks was refined in order to develop a proposed preservation protocol specifically for inter-hull spaces. Changes and refinements to the U.S. Navy tank preservation protocol were made based upon a review of commercial preservation practices and input from coating manufacturer representatives on the best available coating technology.

The guides were developed by consolidating the best coating preservation practices of shipyards and procedures and/or requirements imposed by the classification societies and those recommended by coating manufacturers. Information from existing American Society for Testing and Materials (ASTM) standards and guides, coatings industry literature, and previous research papers was used as reference material to establish the details of each guide.

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CHAPTER 4

VAPOR PHASE CORROSION INHIBITORS

Vapor Phase Corrosion Inhibitors (VPCIs), also known as Vapor Phase Inhibitors (VPIs) and Volatile Corrosion Inhibitors (VCIs), are corrosion inhibiting compounds which are transported as vapors to the surface to be protected. Through interaction with existing corrosion, oxidized VPCIs in the first molecular layer neutralize the affected area. An additional VPCI film layer which forms above the oxidized VPCI molecules, repels moisture, oxygen, and other corrosive agents. VPCIs, unlike traditional protection methods, overcome permeability problems by working at the molecular level with an active barrier. VPCIs are usually used in enclosed spaces to protect metals or alloys from atmospheric corrosion.[7]

Many electrical systems have bare metal surfaces that cannot be treated with traditional coatings. In these situations, VPCI emitters are particularly suitable.[8] VPCIs are transported to the surface to be protected through vaporization. When the equilibrium vapor pressure is reached, the vapors condense to form a crystalline structure on the surface to be protected. The inhibitor layer is loosely bound to the metal surface by adsorption. However, the force of attraction is not strong enough to prevent the inhibitor from leaving the surface upon removal from the inhibitor saturated environment.

If the inter-hull areas are to remain as voids, the use of VPCIs has limitations.[7] VPCIs have been very successful in relatively small enclosures such as electrical connection boxes, switchboards, and load centers. Transferring this technology into void or inter-hull spaces which may be several hundred or thousand square meters in area has not been accomplished and is not recommended until large-scale evaluations of VPCI capabilities are conducted. In addition, due to the intricate design of structural members and the need to evenly distribute the inhibitor concentration over all parts of the inter-hull area, this will be difficult to achieve onboard ships at sea.[9] Vendor data sheets indicate that the most promising VPCI will typically protect bare steel surfaces from corrosion for two years.[10] However, since inter-hull areas may be opened for periodic inspection at intervals shorter than every two years, the VPCI will have to be replenished more frequently than advertised. This is due to their exposure to atmospheric corrosion products because of periodic openings.

If the inter-hull areas are to be used as ballast and are preserved with VPCIs, environmental considerations will prevent the pumping of contaminated water overboard (chromates, phosphates, etc.). This will severely restrict the operational configuration of the ship.

The requirement for a continuous supply of inhibitor vapor for replenishment, the high costs associated with replenishing VPCIs in large inter-hull spaces, and the potential use of the inter-hull space as a ballast tank illustrate the incompatibility of VPCIs as a corrosion control method for the inter-hull areas of double hull ships. If however, the inter-hull space will be utilized as a dry void and will not be ballasted nor opened frequently, the use of

VPCIs in combination with a coating system may attain corrosion protection of greater than ten years.[7]

CHAPTER 5

SPRAY METAL COATINGS

Thermal spray for corrosion protection is normally applied by either the wire flame (combustion) or wire arc process. The metal wire is fed into a gun and melted either by a flame (normally oxy-acetylene) or an electric arc. The atomized particles are propelled by means of compressed air onto the surface, where they cool, forming layers of splat-quenched particles. Wire spray aluminum (WSA) or flame spray aluminum (FSA) are the most popular spray method coating. Coating systems with an aluminum base offer greater corrosion protection and reduce shipboard maintenance. The application of a sealer or topcoat provides the coated surface with long-term protection. These coatings also provide electrochemical (cathodic) protection, particularly during exposure to an aggressive marine atmosphere and in proximity to dissimilar metals.

Field tests were conducted in Norway on steel piles coated with aluminum thermal spray followed by a wash primer, a coal tar vinyl paint, and then a topcoat. After one year or less, in spite of the organic coatings, blisters appeared in the coatings on all the piles in the splash zone. The failure analysis indicated that the major contributing factor was inadequate adhesion between the steel and aluminum thermal spray coating due to poor surface preparation.[11]

For marine applications, thermal spray aluminum coatings are normally 180 to 250 μm (7 to 10 mils) thick in order to limit through porosity (too thin a coating) and to minimize thermal expansion mismatch (too thick a coating) with the substrate which would result in bonding separation. However, even with the inherent advantage of cathodic protection of WSA or FSA compared to typical coating system such as epoxy, the use of metal sprayed coatings for the inter-hull spaces of double hull ships is not feasible and is not recommended. This conclusion is based upon the following requirements for the proper application of metal sprayed coatings:

• The substrate must be abrasive blasted to a white metal finish in accordance with Steel Structures Painting Council (SSPC) SP 5 standard.[12,13] The surface, when viewed using a magnification of ten times, shall be free of oil, grease, dirt, visible mill scale, rust, corrosion products, oxides, paint, or other foreign matter. This requires that all prepared surfaces shall be handled only with clean gloves, rags, slings, and so forth. If the substrate cannot be cleaned such that all rust and oil are removed, the thermal spray coating will not remain attached for long.

• Due to the configuration and size of the inter-hull areas, abrasive blasting must be completed manually and not automatically.

• Metal spray operations have severe time constraints. Metal spray application shall be started within approximately 2 hours, and finished within 4 hours after anchor-tooth surface preparation for steel has been completed.[13]

• Metal spray systems are much more complex than conventional paint systems. A metal spray system requires more component parts than a conventional paint system, each component being more complex than its counterpart in a conventional paint system.

• Training and certification requirements for operators are much more detailed than conventional painting operations.

• Metal spray coating application costs are approximately two and a half times the cost associated with using a conventional paint system.[11]

Metal spray coatings do offer corrosion protection for other areas of the ship. This corrosion protection method has been used for topside weather equipment, machinery spaces, and interior wet spaces. Specifically, these categories include auxiliary exhaust stacks; diesel headers; steam valves, piping, and traps; boiler skirts; stanchions, pipe hangers; rigging fittings; lighting fixtures; ladders; hatches and scuttles; boat davit machinery components; bilges; and machinery foundations. For marine atmospheric service, the use of thermal spray aluminum coatings is an outstanding method of corrosion control.

CHAPTER 6

PRESERVATION PROTOCOL FOR THE INTER-HULL SPACE

In an effort to address and correct the costly corrosion problems occurring in U.S. Navy ships, the Naval Sea Systems Command (NAVSEA) and the Fleet Maintenance Officers established a program. The program is called Engineering for Reduced Maintenance, or ERM. This program has been in place since March 1993 with its emphasis on applying quick corrective solutions to Fleet identified corrosion problems. One of the first problems identified by the Fleet was the frequent requirement to represerve tank coating systems during periodic maintenance cycles. Significant savings could be achieved by the U.S. Navy if the service life of tank coatings could be increased by approximately three times to match the worldwide trend and extend the tank coating service life to 15 to 20 years.

To solve this problem, the U.S. Navy, specifically the Materials Engineering Group of NAVSEA, sought to determine the tank preservation procedures of the shipbuilding industry, both nationally and internationally. After visits to shipyards and coatings manufacturers, and reviewing numerous new building specifications, classification society guidelines and recommendations, NAVSEA concluded that a 15 to 20 year service life could be achieved for tank coating systems.[7,9, 14-18] To obtain this service life, NAVSEA developed a protocol based upon the requirement that specific steps and procedures are essential during the surface preparation and coating application processes. This protocol was modified to specifically address the environmental conditions expected in inter-hull spaces and includes technologically improved coating systems recommended by the coating manufacturers. The essential elements of the inter-hull preservation protocol are:

- Radius all edges, drain holes, coaming, hand holds, foot holds, ladders, etc. to a radius of 3 mm;

- Smooth welds and remove weld spatter;

- Reduce soluble salts on the substrate to less than 3 $\mu g/cm^2$;

- Maintain relative humidity to 50% or less throughout the surface preparation and coating application processes;

- Apply two coats of the light colored, high build, high solids epoxy coating system;

- Apply two stripe coats to areas not accessible to the paint spray gun; and to coating failure susceptible areas such as edges, weld seams, pipe hangers, foot holds, etc. after the first full coat and prior to the topcoat.

Appendices A and B provide the step-by-step procedure for the proposed inter-hull preservation protocol.

6.1 Edge Radiusing

It is a well-known observation in the structures painting community that when a coating is applied to sharp edges, the coating will draw away from the sharp edge leaving it with relatively poor coating coverage relative to the remaining flat surfaces. There is strong evidence that suggests radiusing or chamfering sharp edges will promote improved coating performance.

There are a significant number of references which suggest that edge rounding or chamfering to some degree, offers a benefit of improved coating life. References include:

• National Association of Corrosion Engineers (NACE) Standard RP0178-91[19] recommends practices for the design, fabrication, and surface finish of metal tanks that are to be coated for corrosion resistance. These recommended practices are considered necessary by coating suppliers, applicators, and users of such tanks based upon experience. This NACE Standard states that all sharp edges and weld fillets shall be ground to a smooth radius of at least 3.0 mm with 6.0 mm preferred.[19]

• DTRC Report 87/026,[20] "Paint and Corrosion in SSN 688 Class Submarine Tanks" documents the inspection of five submarines in dry dock to determine if the lifetime of the tanks could be extended from 8 or 9 years to 15 years with touch up permitted every 3 years. The report noted significant metal loss due to corrosion observed along the stiffener edges in two of the submarines inspected.

• National Shipbuilding Research Program sponsored a study to investigate edge effects on coating life in 1983[21] and 1985.[22] Phase I of the study indicated no clear consensus of proper edge preparation, rounding or chamfering.[21] Grinding tools were not specified in any of the reported literature. Phase II of the study revealed that flat plate coating performance on 6 mm (1/4") thick plate requires a minimum 3.2 mm edge radius. For thicknesses less than 6 mm the relationship is the radius of the edge should be 0.5 times the thickness of the plate. For plates thicker than 6 mm, a limit of 3 mm (1/8") should be imposed for edge rounding. The edge performance of the coating systems decreased with decreasing edge radius.[22]

• The SINTEF Group in 1993 recommended all sharp edges be rounded by grinding to a minimum radius of 2 mm.[9] Radiusing is performed prior to priming.

• Det Norske Veritas Classification guidelines for corrosion protection of ships state all sharp edges on cut or burnt steel plates should be rounded or broken before blast cleaning operations.[14] A minimum rounded edge is obtainable by means of a single pass of a grinding tool over the steel edge, breaking up a 90 degree or sharper edge into two, each approximately 90 + 45 = 135 degrees. Det Norske Veritas Classification goes on to say that rounding of sharp edges can also be specified more accurately by providing a minimum radius.[14] No minimum radius is given in the Det Norske Veritas guideline.

• In their specification for water ballast tanks, Nippon Kaiji Kyokai ClassNK recommends that a gas cut free edge be ground three times, thereby reducing the sharp 90 degree edge.[15]

• Hempel Paint in their analysis[23] concluded that edges do cause a reduction in the Dry Film Thickness (DFT) of standard solvent borne epoxy coatings to edges. Hempel concluded rounding is more effective than breaking (chamfering) the edge and their data indicated that a 2 mm radius is significantly more effective than a 1 mm radius. Hempel recommended edges be ground to a minimum 2 mm radius so that the specified film thickness can be built up.

• International Paint recommended that working procedures state that sharp edges or gas cut edges should be removed with a grinder or disc sander by breaking the edge three times.[16,24]

• Jotun Protective Coatings' A Guide to Ballast Tank Protection[17] recommends rounding of sharp edges to a radius of 2 mm.

• Kvaerner Masa Yard and Danyard Shipyard in Europe utilize bulb flats for structural stiffeners thereby reducing the need to round edges.[25,26] Both shipyards use disc grinders to manually round those edges which require such a treatment.

• Two U.S. shipyards, Bath Iron Works and National Steel & Shipbuilding Co., smooth the edge with one pass typically by use of a disc grinder.[27,28] Avondale Industries, Inc. Shipyard Division "knocks" the edge off in 3 passes.[29]

• Two Japanese shipyards, Namura Shipbuilding Company, Ltd. and Sasebo Heavy Industries Company, Ltd., break the edge with one pass using electric or air operated grinders.[30,31] Maehata Shipbuilding Company, Ltd. rounds the edge to 2 to 3 mm.[32]

• Korean shipyards smooth the free edge by grinding or stipulate that the free plate edge shall be broken by grinding with a minimum radius of 1 mm.[33,34]

Clearly, the need to remove sharp edges is essential for avoiding the pullback of a coating system and subsequent thinning of the coating system along these edges. To ensure the rounded edge is provided with a proper profile to accept the coating system, the edge rounding step shall be performed prior to abrasive blasting of the surface. The 2 mm radius is concluded to be too small to enhance the performance of the coating along the edge. In view of the literature cited above, all edges are recommended to be rounded to a minimum radius of 3 mm.

6.2 Weld Smoothing and Weld Spatter Removal

In the process of erecting steel structures and fabricating ship modules, hulls, and tank spaces, extensive welding must be performed. Welding techniques are varied. However, they include basic hand gas/arc welding as well as automated welding processes. Defects such as weld spatter, weld undercuts, rough weld seams, and weld blowholes are inevitable by-products of the welding process. Good painting practice dictates that removal of weld spatter and grinding of rough weld seams be performed to provide a better surface for paint application as well as a higher expectation for improved coating service life.[7,9,14,17,19]

The requirement for no skip welds, weld spatter, rough welds, gouges, undercuts, and other welding imperfections is clearly described in a number of references. This requirement is stated in most coating manufacturer's guides for surface preparation,[16,17,23,24,35] in European shipyard surface preparation requirements,[25,26] in U.S. shipyard surface preparation requirements,[28,29] in a Japanese shipyard surface preparation requirement,[30] in SINTEF's recommendations for pre-treatment of the steel member prior to painting,[9] and in a NACE standard on the fabrication details for tanks for immersion service.[19] This requirement has recently been included in a new coating rule by the International Maritime Organization (IMO).[36]

Clearly the need to remove weld spatter and weld defects is essential for optimizing the performance of the coating system. In view of the literature cited above, it is imperative that weld spatter be removed and that all weld defects such as gouges, undercuts, and surface irregularities be repaired prior to the application of the coating system.

6.3 Reduction of Soluble Salts

The type of water soluble salts on the steel substrate usually is indicative of the storage conditions of the steel. Normally, sodium chloride, calcium carbonate, and ferrous sulfate are present on the steel's surface in varying concentrations and ionic combinations. These ionic species make up the bulk of soluble matter on the steel substrate. However, there are other ionic species, such as zinc, potassium, magnesium, sulfide, and phosphate, which are generally found in lower concentrations than the first group.

Surface contamination with chlorides has been shown to lead to rapid blistering of organic coatings in immersion conditions. Wicks *et al.* discuss several theories in detail in "Organic Coatings, Volume II".[37] The basic mechanism proposed relates to osmotic pressure developed under the coating which acts as a semi-permeable membrane. This osmotic pressure causes some of the solvent from the more dilute solution to diffuse through the semi-permeable membrane towards the more concentrated solution side to slowly dilute it.

This diffusion in one direction will continue until the two solutions have the same concentration or the more concentrated solution is pressurized enough to physically oppose the osmotic diffusion process. During the formation of coating blisters, osmosis causes pressure to build up at contamination sites. If this pressure exceeds the adhesion of the coating, it lifts the coating at that point and forms a blister. The blister then continues to grow until equilibrium is reached, either by solution dilution or a build up of pressure inside the blister, to resist further flow into it. Such effects are often drastic when the immersion is in distilled water which will promote osmotic blistering more so than sea water.[38,39]

It should be noted that not all blistering is caused by osmotic forces. Martin *et al.*[40] relate blister formation to a defect controlled process in their "Non-Osmotic, Defect Controlled Cathodic Disbondment of a Coating From a Steel Substrate". Even in the absence of osmosis-driven blistering, surface salt contamination may create problems with corrosion control. The corrosivity of any electrolyte that collects at the coating/surface interface is likely proportional to its conductivity. Soluble salts on the surface would likely increase the conductivity and corrosivity of any local electrolyte.

Chlorides are generally considered to have the most significant effect on the performance of coatings applied to metallic structures such as inter-hull spaces. In fact, theoretical and empirical evidence indicates that surface chlorides can cause premature failure of various coating systems. This research has been sponsored by many different organizations in the U.S. and abroad.

The literature reviewed was generally from the marine, shipbuilding, and highway industries. The references most useful for the maritime industry come from studies sponsored by the Federal Highway Administration entitled "Effect of Surface Contaminants on Coating Life"[41] and by the National Shipbuilding Research Program entitled "The Effects of Substrate Contaminants on the Life of Epoxy Coatings Submerged in Sea Water".[39]

Various "ceiling" values have been determined for the maximum tolerable level for surface chlorides. These values range from 0.6 $\mu g/cm^2$ up to over 100 $\mu g/cm^2$. The reported values differ depending on the test procedure of the researcher, the surface chloride extraction procedure used during testing, the type of coating applied, and the type of test exposure after coating application. However, most of the values reported in the literature for epoxy coatings fall in the range between 5 and 10 $\mu g/cm^2$.[9,16,23,35,39]

A threshold level of 3 $\mu g/cm^2$ is selected as the maximum level of surface salt contamination for marine epoxy systems. This threshold level incorporates a safety factor of two for the lower end of reported values for chloride contamination. It has been readily achieved by near-white metal blast cleaning (SSPC-SP 10), for the application of epoxy paint in U.S. Navy ship ballast tanks.[18, 42-45]

6.4 Dehumidification

Manufacturer instructions and Naval Ships' Technical Manual (NSTM) Chapter 631[46] outline the environmental condition requirements during paint application that must be met to optimize coating performance. For epoxies, unless manufacturer's instructions state otherwise, it is essential that the substrate and surrounding temperature be between 2 and 35 degrees C (35 and 95 degrees F). NSTM Chapter 631 further states that "paint should be applied only when surfaces are completely dry and surface temperature is at least 5 degrees F above the dew point" and that the wind velocity should be less than 24 kilometers per hour (15 miles per hour) and the relative humidity less than 85%.[46]

Research has shown that the corrosion rate of steel tends to accelerate at relative humidities above 60%.[7,23,24,47] Corrosion rates are correspondingly low at levels below 50% to 60% relative humidity. If the environment inside the tank cannot be controlled such that moisture condensation on the steel surface is prevented, regardless of ambient weather conditions, then flash rusting can occur. The control of the interior environment to prevent this is possible and, in fact, one can "hold" a blasted tank or inter-hull space indefinitely until the time at which the tank or inter-hull space is painted. This process is usually accomplished by continuously forcing dehumidified air into all tank areas, thereby displacing any moisture-laden air. A dehumidified environment can prevent the onset of flash rusting. This saves costly sweep blasting and clean-up operations prior to painting.

Though most coating manufacturers recommend the relative humidity to be less than 85% during coating application, SIGMA Coating prefers the relative humidity to be below 50%[35], and International Paint prefers a level between 40% and 60%.[24] Danyard Shipyard likewise establishes a relative humidity range between 25% and 60%[26] and a French shipyard specifies the relative humidity be less than 30%.[18]

One National Shipbuilding Research Program (NSRP) report[39] emphasized that "the very common practice of lowering the humidity to stop blasted steel surfaces from rapidly turning, does not correct the basic cause of the problem, it only hides it. Dehumidification only retards the flash rusting process temporarily". Despite this finding, dehumidification is still appropriate as an additional defense against flash rusting in the event surface chloride contamination is not removed adequately from the steel substrate. This, however, should not be the case for the inter-hull space since this preservation protocol specifically requires the surface chloride contamination to be 3 $\mu g/cm^2$ or less with a prescribed maximum level of relative humidity.

The relative humidity in the inter-hull space shall be maintained at 50% or less from prior to abrasive blasting to final curing of the topcoat. This level of relative humidity is an added safeguard to avoid the costly step of sweep blasting to remove flash rusting of the substrate prior to coating application.

6.5 Tank Coating Material

Before reviewing any coating system, it is important to understand that no coating can be used or specified in any application for ship structure preservation in the United States unless it meets the Volatile Organic Compound (VOC) content regulations. To maintain compliance, it is logical to consider the strictest set of VOC laws, namely the state of California laws. These laws are expected to be adopted nationally by the Environmental Protection Agency (EPA). The VOC content for all air-dried marine coatings applied after 1

September 1991 is 340 grams per liter. One notable exception is for Inorganic Zinc (IOZ) coatings which were permitted to have a 650 grams per liter limit until 1 September 1994, but are now also regulated to 340 grams per liter. Interestingly, IOZ pre-construction primers are not specifically addressed by the regulations as specialty coatings, and the impact of the regulations on these types of coatings is not clear. Based upon past experience, the maximum allowable VOC is regularly revised to lower limits and the above quoted limits are likely to be reduced in the future.

In selecting a coating system for the inter-hull space, the following general guidelines were followed:

• The protective system selected must be capable of meeting the requirements expected for useful service life, future maintenance, and costs;

• Multi-coat treatments with coating layers of contrasting colors are recommended for better conditions of application and a better final result;

• The final layer of paint should be light-colored to make it easily distinguishable from rust and the onset of corrosion, and thus easier to inspect;

• Two-component products with long pot-life are preferable;

• The coating system selected for the protection of ballast tanks must be compatible with the designed and installed cathodic protection system (exposed to the maximum potential of the cathodic protection system for three months with no evidence of under cutting, peeling, blistering, or other coating system failure);

• Only products accompanied by detailed technical specifications and satisfactory performance records, and supported by appropriate test data should be used;

• The manufacturer of the coating system should be capable of providing adequate technical services throughout the surface preparation and painting evolutions.

With due consideration for VOC compliance, a proven track record of corrosion performance, and a flash point of greater than 38 degrees C (100 degrees F), Hack *et al.*[7] evaluated 28 commercial coatings. The majority of coatings evaluated were high solid epoxies, which is not surprising since they have been favorites among shipbuilders and ship owners. Their results indicated that coating systems are currently available which initially appear to perform better than the standard Navy Formula 150/151 epoxy (MIL-P-24441). Yet, results of long-term exposure tests indicate that high solid epoxy coatings are the preferred system for double hull application.[48]

A few technical references cite the epoxy-polyamide chemistry as the best performer of the epoxy type systems for water immersion service.[22,49-51] The literature data points to the following physical parameters of epoxy-polyamides as being important to their inherent excellent performance in water immersion applications:

• Adhesion - In general, epoxy coatings demonstrate better adhesion to metal substrates than most other common generic marine coating types. The good adhesion shown by epoxies derives from the hydrogen bonds developed by their polar hydroxyl groups and their good surface wetting properties when properly formulated. Adhesion is a key performance parameter for barrier coating systems since it directly affects the propensity for the coating to delaminate in the area surrounding defects.[52]

• Low Water/Ionic Permeability - Polyamide cured epoxies demonstrate excellent resistance to permeation by water and aqueous ions due to the high cross-link density of the cured film. This resistance tends to slow the migration of water molecules through the paint film and prevent the migration of potentially corrosive species from the seawater contained in the tank to the bare steel surface beneath the coating.[52]

• Relative Surface Tolerance - The excellent wetting nature of epoxy-polyamide, the use of water displacing solvents, and existence of polar groups within epoxy-polyamide coatings makes them inherently more tolerant of minor amounts of surface moisture than coatings that cure through a "drying" process. In addition, although performance of any coating is highly dependent upon surface cleanliness, the epoxy-polyamides will perform better on less-than-ideal surfaces than many other high performance type coatings. This quality provides a practical safety factor when applying coatings in the often less-than-ideal shipyard environment.[52]

• Durability - The highly cross-linked structure of epoxy-polyamide coatings make them more durable and abrasion resistant compared to other generic types of marine coatings. This quality is important for immersed surfaces such as inter-hull spaces being used as sea water ballast tanks which operate in uncontrolled and unfiltered water.[52]

For epoxy-polyamide type coatings, laboratory studies have shown that the deterioration rate of a coating in service is not linear with time. Data has shown that U.S. Navy approved epoxy-polyamide coatings' rate of moisture absorption, as indicated by capacitance measurements, is logarithmic with time. In other words, as the thickness of the paint is doubled, theoretically a ten-fold increase in the coating life can be expected. Though, in actual shipboard application, this may not be the case; it does seem reasonable to expect an extension in the life of the coating system if the coating system thickness is increased. Additionally, in barrier-type coatings, the thickness of the coating system has shown to be a good predictor of impending coating failure.

Also, Dr. Ingenior has shown that the rate of underfilm disbondment in short term tests is inversely related to dry film thickness (DFT) for epoxy type paints, with the rate being reduced by a factor of about three when the coating thickness is increased from about 75 to 300 microns (3 to 12 mils).[53] In the same work, it was shown that the ionic transfer resistance (coating resistance) also reached a maximum after exceeding a minimal dry film thickness of about 100 microns (4 mils) for an epoxy coating. In addition, the Leidheiser and SINTEF reports of December 1992 both detailed that a minimum coating resistance is necessary for the performance of the barrier coating.[54,55] In other words, there is a minimum required dry film thickness for the coating system to properly provide protection to the steel substrate.

Wicks *et al.*[37] suggest that maintenance coatings ought to be applied at thicknesses greater than 400 microns (16 mils) to insure long life. If for no other reason, the greater thickness and a two coat application reduces the chances for a coating defect to extend throughout the coating thickness.[6,14,15,18,51]

However, there is a significant concern for high build coating thicknesses of 250 microns (10 mils) dry film thickness or greater. This concern is addressed by ensuring proper curing and avoiding runs, sags, and solvent entrapment. Excessive thickness, above the specified amount, will usually degrade the performance of the coating, not enhance it.[36,56] Adequate ventilation and compliance with the manufacturer's instructions should be followed to avoid any occurrence of solvent entrapment and improper curing of the coating system. This concern can be avoided by utilizing a 100% solids epoxy coating system.

Numerous coating manufacturers recommend the use of high solids epoxy coatings in seawater ballast tanks with solids content ranging from 80% to 100%.[16,17,23,35] Additionally, both European shipyards visited and a French shipyard's report documenting 15 years of experience in painting ballast tanks confirm application of relatively high solid epoxy systems in their ballast tanks.[18,25,26] It is noteworthy that despite the added cost in some cases to use special equipment to apply 100% or near 100% solids coatings and the increased difficulty to apply these coatings in confined areas within the inter-hull area, ship owners and shipyards still continue to specify these coating systems for the inter-hull space due to their superior performance. Other reports from Europe confirm the use of epoxy systems in ballast tanks.[6,14] The SINTEF report recommended for the best corrosion protection of ballast tanks, epoxy-based systems in light colors be applied to blast-cleaned substrates.[9] All U.S. shipyards visited also apply epoxy systems to their ballast and fuel tanks.[27-29,57,58] Coal tar epoxy coatings which are no longer authorized for use in the U.S. shipbuilding industry, are still used and recommended by the Japanese shipbuilding industry.[15,30]

In the past, an easy coating selection has been the use of soft coatings for the maintenance of ballast tanks in older vessels. However, these systems tend to hide problems rather than cure them; and subsequent tank inspections will be extremely dangerous in view of their slippery nature, in particular the lanolin products applied in 500 to 1000 microns (20 to 40 mils) DFT.

The compartments of ballast tanks are difficult, narrow areas, and light conditions can have a significant impact on the standards of application. A black tar epoxy paint creates the worst possible condition as it "steals" light and the painter will have a difficult time seeing during the painting operation. Supervisors controlling the work and inspectors who must inspect the ballast tanks will be hindered by the poor lighting condition. To prevent this occurrence, coating manufacturers[6,17] and Det Norske Veritas[14] recommend the top coat of the coating system be light colored to facilitate inspection of the coating application process and the material condition of the coating system during future inspections. The use of light colored coatings also provides the added benefit of quicker inspection times, therefore reducing the time out-of-service for the vessel.

Another consideration in the selection of the inter-hull space coating system is its compatibility with the pre-construction primer used. In all cases, if the pre-construction primer is not compatible with the epoxy coating system, it shall be removed by abrasive blasting to SSPC-SP-10, near white metal. This requirement may be waived when the coating manufacturer of the epoxy coating system recommends otherwise and acknowledges that there will be no degradation in performance of the epoxy coating system. In this specific situation, all markings on the pre-construction primer shall be removed by abrasive blasting to SSPC-SP-7, brush off blast clean, prior to the first coat of the epoxy coating system.

With due consideration for performance, thickness, ease of inspection, and avoidance of solvent entrapment; a 100% solids light colored epoxy coating system of two coats, each coat at 250 microns (10 mils) dry film thickness, is recommended for the inter-hull space.

6.6 Edge Stripe Coating

The necessity for stripe coating resides in the nature of the coating being applied. Apart from the many excellent characteristics of epoxy coatings, one of their shortcomings is the lack of good edge coverage. This is because after the coating is applied, there is a tendency for it to pull away from the edge. This results in a much thinner coating along the edge and one that offers a reduced barrier coating for the steel substrate. Since edge failure is the leading cause of tank coating failure, additional steps are required to resolve this problem. One step is the application of stripe coats along edges, welds, and difficult-to-reach areas.[7,9,16-18,23-26,33-35,38,50,59,60]

The National Shipbuilding Research Program reports entitled "The Effect of Edge Preparation on Coating Life"[21,22] discussed stripe coating and performed tests to derive quantitative data. The results of the 229 day immersion and 60 day salt fog tests revealed that stripe coating with a brush and airless spray performed worse than with airless spray alone. Brush coated edges suffered from paint chipping due to excessive build up and inconsistent thicknesses. However, airless spray cannot be used on all locations. All spray methods have an inherent disadvantage of not providing adequate coverage on the back side of edges due to shadow effects.

The SINTEF Group report[9] discusses the necessity to use only a brush for stripe coating. They recommend the application of the first stripe coat after the first coat of primer has been applied over the freshly blasted steel. The SINTEF Group specifically warned against the use of a roller or spray as a means of applying the stripe coat.

Avondale Industries, Inc. Shipyard Division has had success with stripe coating using high volume low pressure equipment.[29] National Steel & Shipbuilding Co. prefers to brush apply their stripe coats, rather than use either spray or high volume low pressure equipment.[28]

In comparing stripe coating to radiusing, Hempel Paint Company concluded that a stripe coat is especially beneficial over a sharp edge.[23] As the sharpness of the edge decreases, the effectiveness of the stripe coat decreases to almost no added value. International Paint recommends the stripe coats be applied by brush or roller.[24] Det Norske Veritas Classification Society also recommends two stripe coats with brush be applied in ballast tanks.[14] This application method is also endorsed by Deere.[51]

The benefits of stripe coating to extend the service life of a tank coating system is clearly indicated in the literature. Based upon the literature cited above, a stripe coat shall be applied to all edges, welds, and difficult-to-reach areas for each coat of the coating system specified. However, the literature is not definitive and is often conflicting on the recommended application method for striping. Therefore, for the preservation protocol for the inter-hull space, stripe coats shall be applied in accordance with the coating manufacturer's recommended method and be of contrasting color to the colors of the first and top coats. Depending on the size of the inter-hull space, the first stripe coat is recommended to be applied after the first coat. The stripe coat associated with the top coat shall be applied prior to the application of the top coat. This is to ensure the tank or void is finished with one uniform light colored coat of paint to enhance all visual inspection requirements. Allow sufficient drying time per the coating manufacturer's instructions between all stripe coat applications.

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Chapter 7

CATHODIC PROTECTION

Cathodic protection is a method of protecting a metal surface from corrosion by opposing the electrical current flow that would naturally occur as part of the corrosion process. This is accomplished by use of either sacrificial anodes or impressed current. Both systems can be used in combination with coating systems to prevent or reduce corrosion. Sacrificial anodes are composed of relatively active metals that will preferentially corrode (sacrifice) and in the process protect the structural metal, usually steel. In theory, any metal listed in the galvanic series (see Table 7.1) which is more electronegative (active) than another may provide cathodic protection for the more electropositive (noble) metal. This is the basis for marine sacrificial anode cathodic protection systems. Zinc and aluminum are the most common materials for sacrificial anodes used in cathodic protection systems designed to protect steel structures and components in marine environments. Iron alloys are often used as anodes to enhance the corrosion resistance of copper alloys.

TABLE 7.1 Galvanic Series of Metals

Corroded End - Anodic or less noble (Electronegative)
Magnesium
Zinc
Aluminum
Cadmium
Iron or Steel
Stainless Steels (active)
Soft Solders
Tin
Lead
Nickel
Brass
Bronzes
Nickel-Copper Alloys
Copper
Stainless Steels (passive)
Silver Solder
Silver
Titanium
Gold
Platinum
Protected End - Cathodic or most noble (Electropositive)

Table 7.2 lists the typical electrochemical properties of the materials commonly used for anodes in marine applications. The anode supplier should be consulted for actual values.

TABLE 7.2 Anode Material Electrochemical Properties

Anode Material	Potential Voltage vs. Ag/AgCl (volts)	Efficiency (%)	Anode Consumption (lb/amp-yr /kg/amp-yr)	Density (lb/in^3 / kg/m^3)
Magnesium	-1.55	50	17 / 7.9	0.063 / 1744
Aluminum	-1.06	93	7 / 3.2	0.099 / 2740
Iron	-0.60	N.A.	20 / 9.1	N.A.
Zinc	-1.04	99	24 / 10.9	0.258 / 7141

N.A.: Not available

The literature clearly espouses the virtues of a sacrificial cathodic protection system combined with a hard barrier coating system.[3,9,23,36,59,61] The current trend is to design to a higher current density with emphasis on distributing the sacrificial anodes at locations which prevent potential problems.

Impressed current cathodic protection replaces the sacrificial anode with an external direct current power source that supplies this current through a specially designed inert anode.

Sacrificial anodes are currently the best method for providing cathodic protection in areas where velocity effects and current demand are minimal, when the space is normally wet more than 25% of the time, and when weight concerns are not critical. Inter-hull spaces which are used for ballast fit this description.

The design of a sacrificial anode cathodic protection system is concerned primarily with determining the quantity (weight) of anodes required. The layout of the sacrificial anodes is based on empirical data and experience. Factors affecting design of a sacrificial anode cathodic protection system include: total surface area to be protected, maximum coating damage allowed, and the driving potential.

The total surface area should be determined through the calculation of each inter-hull space that will require protection. All coatings can be expected to exhibit failure with time. As the coating fails, the exposed base metal area requiring cathodic protection increases. An estimate of either the allowable, or expected paint damage that may occur during the service interval is required to properly design a cathodic protection system.

In addition, the type of sacrificial anode material and the type of material to be protected are determined. In most cases for inter-hull spaces, zinc or aluminum sacrificial anodes are selected for the steel substrate.

For inter-hull spaces, the flow conditions for purposes of cathodic protection system design will be low flow or stagnant conditions. Based upon this condition, the required current density is 0.0023 amperes per square meter.

The maximum driving voltage is the voltage of the system when new anodes are installed, when paint damage occurs, and when anodes are cleaned. For steel surfaces protected by either zinc or aluminum anodes, the maximum driving voltage is 0.45 volts DC. Since this is the potential difference between two materials, there is no need to stipulate the type of reference electrode. For bronze and copper-nickel surfaces protected by either zinc or aluminum anodes, the maximum driving voltage is 0.80 volts DC. See Table 7.3.

TABLE 7.3 Driving Potential (volts DC)

	Sacrificial Anode Type	
Substrate Material	Zinc, Aluminum	Magnesium
Steel	0.45	1.00
Bronze, Copper Nickel	0.80	1.35

Even given the above assumptions and parameters, the design of a proper cathodic protection system in a ballast tank is not easy. Each area of the tank has its own unique problems. A study by EXXON of all its 46 owned VLCC/ULCCs indicated that in segregated (clean seawater) ballast tanks, wastage of the steel was most severe in the splash zone where breakdown of the coating first occurs.[62]

7.1 General Guidelines

The following general guidelines should be considered when designing a sacrificial cathodic protection system for ballast tanks:

• Anodes should be installed and distributed in such a way as to provide good coverage for the entire area. They should be welded on or bolted to lugs.

• It is particularly important to protect horizontal surfaces at the bottom of the tanks and structural members.

• An anode will normally protect surfaces in direct "line of sight". Surfaces behind stiffeners, around corners, and inside pipes will not be adequately protected.

• Sacrificial anode cathodic protection is effective for tanks that are continuously or frequently immersed in water. The parts of the tanks not submerged, such as the top of the tanks, are not protected by the cathodic protection system.

• Tank bottoms which contain standing water are particularly liable to suffer from pitting. In these areas, anodes should be installed on the bottom of the tank.

• Locate anodes in such a way that they can be easily washed down to remove sludge and other deposits.

• For tanks with a large number of small sections and compartments, install at least one anode in each small compartment.

• Aluminum anodes deliver more current per unit weight than zinc and therefore are a better choice in financial terms.

7.2 Design Methodology

The design methodology calculates the minimum number of anodes required, using the following steps:

• Calculate the required current for cathodic protection using surface area, percent paint damage, and required current density.

• Calculate the amps per anode based on driving voltage and anode type.

• Calculate the number of anodes required.

To calculate the required current for cathodic protection using the surface area, percent paint damage, and required current density, use the following equation:

$$I_{required} = (SA_{total})\ (\text{Percent Paint Damage})\ (i_{required})$$

where $I_{required}$ = current required for cathodic protection

$i_{required}$ = current density required for cathodic protection (amps/area) per Table 7.4

SA_{total} = total surface area to be protected

Percent Paint Damage = allowable paint damage as a percentage of the total surface area

TABLE 7.4 Required Current Density For Steel

Area Units	($I_{required}$/unit area) = $i_{required}$ (amps/unit area)
Square Feet	0.025
Square Meters	0.2691
Square Centimeters	2.69×10^{-5}

To calculate the amps per anode based on the driving voltage and anode type, look up the driving potential of the anode type based upon the substrate material in Table 7.3. Calculate the exposed surface area of one anode. The exposed surface area is assumed to be the top and four sides of the anode. The underside of the anode is not an exposed area and is therefore not included in the calculations for the exposed surface area of an anode. Calculate the current output per anode using the following equation:

$$\text{Log}(I_{anode}) = 0.727 \text{ Log (Anode Surface Area)} + \text{Log}(E) - K$$

where I_{anode} = current output per anode in amps

E = driving potential in volts DC from Table 7.3

K = a constant based upon the units of measurement employed

K = + 1.188 if anode area in square inches
= - 2.469 if anode area in square centimeters
= + 0.439 if anode area in square meters

Now calculate the number of anodes required, using the equation:

$$N = (I_{required})/(I_{anode})$$

N shall always be rounded up to the next higher integer number. N is also the minimum number of anodes required. The number of small, independent pockets in the tank bottom, which reduces the range of effectiveness of each anode, may increase the number of anodes required.

Example: Inter-hull area of 10,000 square feet designing to a 10% coating failure using zinc anodes with dimensions of 6" x 12" x 2.5"

Therefore, SA_{total} = 10,000 square feet and from Table 7.4, $i_{required}$ = 0.025 amps per square feet.

Calculate $I_{required} = (10{,}000)(0.10)(0.025)$

$$I_{required} = 25 \text{ amps}$$

Anode Surface Area = $(6 \times 12) + 2(6 \times 2.5) + 2(12 \times 2.5)$
= 162 square inches

NOTE: The surface of the sacrificial anode in tight contact with the substrate is not included in the effective anode surface area calculation.

The driving potential for a zinc anode on a steel substrate from Table 7.3 is 0.45 volts DC and K is 1.188 if the anode area is in square inches.

Therefore,

$$\text{Log}\,(I_{anode}) = 0.727\,\text{Log}\,(162) + \text{Log}\,(0.45) - (1.188)$$

$$\text{Log}\,(I_{anode}) = 0.0715$$

$$I_{anode} = 1.179 \text{ amps}$$

Calculating $N = (25)/(1.179)$

$N = 21.2$ and rounding up,

$N = 22$ anodes

7.3 In-Service Inspection

The protection potential of a cathodic protection system can be measured in a tank by lowering a standard reference electrode which is connected to a voltmeter and reading the potential difference between the reference electrode and the adjacent steel surfaces. This will require the tank to be full of seawater. The potential gives a value which represents an average protection for the tank. This may make it difficult to assess if some local areas are well protected and others are not. However, these potential measurements provide important indications of the condition of the tank.

Several types of reference electrodes may be used. The reference electrode is connected to the negative contact of a DC millivoltmeter with an input impedance of about 10^4 $M\Omega$. No current should pass through the reference electrode. The positive contact is connected to the steel (i.e. at the top of the tank where measurements are being made). The reference electrode is moved to a number of positions, but not near a sacrificial anode. These measurements should be conducted while the vessel is in operation in order to be able to follow up how its condition changes with time.

When the tank is empty, check the anodes and determine if they are being consumed or whether they have been passivated. An even distribution of calcareous deposits indicates that the cathodic protection system is working well. Zones lacking deposits are normally indicative of insufficient protection.

7.4 Service Life

The service life of sacrificial anodes is dependent primarily on current output of the anode and mass of the anode. Current output, in turn, is dependent on the amount of bare metal being protected, electrolyte resistivity, velocity, and temperature.

Traditional application of anode consumption rates are based upon assumed current demand and driving potential. This assumption is adequate for anode service life up to 6 to 7 years. Prediction of anode service beyond 7 years is not considered reliable. Therefore, periodic inspection and/or monitoring is required beyond 7 years of service life.

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CHAPTER 8

SURFACE CONTAMINATION DETECTION

Soluble salts on steel substrates cause premature coating failure.[37,39] It is important for the ship owner, shipyard, and coating manufacturer representatives to ensure the steel substrate is not contaminated with surface salts. The types of water soluble salts found on a steel surface reflect the environment in which the steel has been stored. Normally, sodium chloride, calcium carbonate, and ferrous sulfate are present on the metal's surface in varying concentrations and ionic combinations.

By knowing the quantitative amount of surface salts on the substrate, appropriate action can by taken by the shipyard to ensure the measured surface salt concentration is below an agreed threshold level. Conductimetric measurement, with results expressed in microsiemens per centimeter (μS/cm), can be a valuable tool for determining salt concentrations.[63]

The Bresle Test procedure is recommended for its portability and ease of use. The procedure outlined below combines the results of three references[23,63,64] and requires a Bresle Kit (available from KTA-Tator, Inc. in Pittsburgh, PA), an electronic conductivity meter, and a thermometer. The Bresle Kit is available in a carrying case and is ideally suited for field measurements. Briefly stated, the procedure to determine the chloride concentration of the steel substrate in micrograms per square centimeter ($\mu g/cm^2$) is:

1. Determine a suitable surface for the test. The surface may be horizontal, vertical, slanting, or somewhat bulging. The surface should be relatively dry without any noticeable dampness.

2. Take one Bresle Sampler (12.5 cm^2) from the equipment case, remove the filler of its compartment and the protective paper label. Press the Bresle Sampler's adhesive side onto the selected test surface. Best results are achieved when the surface temperature is above 10 degrees C (50 degrees F).

3. Insert an empty syringe into the cell via the spongy foam perimeter. Evacuate the air from the cell using the syringe. Bend the syringe needle as required.

4. Insert 10 ml of distilled water with the syringe through the spongy foam perimeter. Hold the perimeter of the cell firmly to avoid leakage of the distilled water.

5. Gently rub the top of the cell to agitate the distilled water in the cell to remove any surface salts and to place the salts into solution with the distilled water. Avoid excessive rubbing to prevent leakage of the liquid from the sampler.

6. After approximately 15 seconds of agitation, remove the 10 mL of liquid with the syringe, then reinject the liquid into the sampling compartment, and then suction the liquid back into

the syringe cylinder. Repeat until at least four cycles of injection and sucking back into the syringe have been completed.

7. At the end of the last cycle, remove and transfer as much as possible of the 10 mL liquid from the sampling compartment to a clean plastic container provided. If leakage occurs from the sampler, the sample obtained shall be rejected.

8. After sampling, clean and rinse the syringe so that it can be re-used. A bent needle is best left as it is until it becomes necessary to straighten it or bend it further.

9. Measure the conductivity of the liquid in microsiemens using an electronic conductivity meter.

10. Measure the temperature of the liquid using a thermometer.

11. Correct the conductivity measurement of the liquid for temperature by using the values of Table 8.1 and the formula,

(Conductivity Reading) x (Correction Factor)

TABLE 8.1 Temperature Correction

Temperature of Liquid (degrees C)	Correction Factor
15.0	1.10
17.5	1.05
20.0	1.00
22.5	0.95
25.0	0.90

12. Calculate the concentration of chlorides in mg/L by using the following relationship:

Concentration in mg/L = K x (Conductivity)

Where K = 0.43 (the average value for sodium, calcium, and ferrous chlorides)

13. Calculate the weight of salt in mg in the 10 mL of extracted liquid by multiplying the calculated concentration in mg/L by the 10 mL volume, and dividing by 1000 (ml/L).

14. Calculate the concentration of chlorides in μg/cm^2 by dividing the weight of the salt in mg by the area of the patch (12.5 cm^2) and multiplying by 1000 (μg/mg).

15. For comparison, calculate the concentration of chlorides in μg/cm^2 of 10 mL of distilled water by repeating Steps 9 through 14 above.

EXAMPLE: Conductivity meter reading is 5 μS.
Temperature of the liquid is 25 ^{0}C.
Volume of the sample is 10 mL.

a. Concentration in mg/L is calculated to be:

$$0.43 \times 5 \times 0.90 = 1.94 \text{ mg/L}$$

b. Weight of salt mg in the 10 mL of liquid is calculated to be:

$$(1.94 \times 10)/1000 = 0.0194 \text{ mg}$$

c. Concentration of chlorides in μg/cm^2 is calculated to be:

$$(0.0194 \times 1000)/12.5 = 1.55\ \mu\text{g/cm}^2$$

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CHAPTER 9

EDGE PROTECTION SYSTEMS

The requirement for portable edge rounding tools is necessary because the U.S. shipbuilding industry practice is to use shapes which normally come with sharp edges. From observations and interviews with commercial shipyards, it is apparent that edge rounding or chamfering is accomplished manually by the use of low pressure air and electric disc sanders or grinders.[25-32] It seemed apparent that the shipyards visited were not interested in improving their efficiency by designing a tool to accomplish the edge rounding requirement. For confined or hard-to-reach areas, the use of smaller high speed die grinders with various attachments to fit the task at hand are recommended. The U.S. Navy is developing an edge rounding tool which will be able to round both edges of a stiffener in one pass. Shipboard evaluation of this edge rounding tool is expected in fiscal year 1996.

As previously reported, all edge rounding operations now are mechanically performed by shipyard workers grinding the sharp edge until a smooth surface is obtained. Research has commenced to evaluate edge protection systems, in lieu of manually rounding the edges which can be applied to the edge after the tank coating system has been installed. This evaluation has been initiated to investigate processes and materials which can offset the relatively high cost associated with manually rounding/radiusing edges. One concept being investigated by the U.S. Navy involves the use of an easy to apply durable coating which is proposed to be applied along these sharp edges. Attributes of this edge coating system include: no additional surface preparation on the edge; easy application; cure time amenable with the tank coating system; excellent breakdown resistance; producible; and reasonably priced.

Initially, tapes were investigated as a potential edge coating system. The concept was to apply the tape along the edge thereby "smoothing" the sharp edge. Several U.S. tape manufacturers were contacted, and their recommendations were evaluated. The technical evaluation concluded that tapes are not suitable as an edge protection system due to application difficulties, inadequate durability of the tape adhesive to tolerate the adverse service conditions, and the increased potential for under-cutting and crevice corrosion along the tape's edge.

Based upon the lessons learned in the tape evaluation, the U.S. Navy recently commenced evaluating the use of mastics, polysulfides, and an epoxy coating system as edge coating systems. The use of mastics and polysulfides is recommended for evaluation based upon the Navy's success in the use of these products in other applications. The selection of the epoxy coating system is based upon the coating manufacturer's product information which advertised the ability to provide good edge covering capacity. Limited laboratory testing by the U.S. Navy confirms the coating manufacturer's claims of good edge covering characteristic of this epoxy coating system.

CHAPTER 10

SENSORS

One method for observing and/or detecting corrosion on ships is by the use of sensors. These are especially useful in areas of restricted or limited access such as the inter-hull space. For inter-hull spaces, sensors can be used to study the onset and rate of corrosion as well as coating breakdown.

All ships suffer from the problems of corrosion. For the inter-hull spacing of double hull ships, which is not always accessible nor monitored regularly, a remote method for monitoring corrosion is desirable. Sensors can be used to oversee this area of the ship, to determine the inception and rate of corrosion. Sensors offer unique advantages in terms of *in situ* sensitivity, small size, and be used to monitor corrosion in environments that have limited access.[65]

Electrochemical sensors make it possible to follow continuously the response of metals to the changes in atmospheric conditions. Such sensors are often constructed as galvanic couples, such as copper/steel, which have the advantage that the galvanic current is easily monitored and no external signal needs to be applied.[66]

Tkachenko[67] has studied the use of measuring corrosion rates by a method based on the recording of currents occurring in a multi-electrode galvanic system composed of electrodes of the same type. This method is based on measurements of the currents in a Tomashov multielectrode sensor, which is an assembly of alternating electrodes of two different metals. Through prior research, Tkachenko concluded that determining the instantaneous corrosion rate can be accomplished.

Sensors have been used to examine corrosion in various materials and environments. They have been used to study the effect of hydrogen in steels, including pipeline steels in sour gas service.[68,69] Two main types of sensors, amperometric[68] and potentiometric,[68,69] were found to be responsive to hydrogen in steel. The amperometric sensor measures the flux of hydrogen through the steel, from which the hydrogen concentration at the inner surface of the steel may be estimated. The potentiometric sensor measures the equivalent pressure of hydrogen in the steel.[69] These sensors can be attached to the external surface of the pipeline to specifically monitor the effects of the hydrogen in steel.

Sensors for the monitoring of corrosion of steel in concrete have been developed.[70] If the corrosion risk for the steel reinforcement is detected early enough, damage can be avoided or significantly reduced through relatively simple protection measures. For this reason, a permanent corrosion monitoring system has been developed which indicates the corrosion risk for the reinforcement in concrete structures.

One company in Germany has developed a corrosion monitoring system which has already been installed into three concrete structures:

- Schiessbergstrasse Bridge near Cologne, Germany
- A bridge near Nötsch, Austria
- Eastern Railway Tunnel of the Great Belt Link, Denmark[70]

Corrosion sensors have also been applied to aircraft.[71-74] Wyman reports that Stropki has coupled these to credit-card sized monitors which provide an early warning of problems.[71] Such corrosion monitoring sensors have been tested on U.S. Air Force aircraft.[71] The system monitors the increase of electrical resistivity in small sensors as the material is corroded away, the thinner the material, the higher the resistance. The important factor is the rate of change.

This sensor system is applicable for use in double hull ships. It is hard wired, but can be connected directly to a computer onboard the ship. A typical sensor is 250 microns thick.[71] It is made of the same material and subjected to the same manufacturing treatments as the structure being monitored. Each sensor is mounted on a glass probe and has an associated reference sensor sealed in glass.

Agarwala reports that some electrochemical galvanic sensors have been successfully used in salt spray chambers and humidity chambers.[72] Meanwhile, Goldfine has been looking at nondestructive inspection techniques, such as ultrasonic and eddy current, and feels that these do not adequately detect the early stages of hidden corrosion under paint in critical structures such as air frames; therefore he has looked at Meandering Winding Magnetometers (MWMs) and Interdigital Electrode Dielectrometers (IDEDs).[73] Additionally, Koch reports on new developments, in addition to existing systems, for monitoring corrosion in aircraft.[74]

Two main types of monitors are linear polarization resistance and electrical resistivity. Since the system being studied will not be immersed at all times, linear polarization resistance monitoring sensors cannot be used. Electrical resistivity monitors are more applicable. They measure the electrical resistivity of the metal being monitored. The amount of change in resistivity is used to determine the rate of corrosion. The resistivity increases as the thickness of the metal decreases. (This decrease in thickness is caused by the metal corroding away.)

There are a few companies which design and sell corrosion monitoring systems. Although not designed as remote monitoring sensors for double hull ships, some of these systems may be applied to the ship's inter-hull areas. A wireless survey system with a digitized analog reader transmitter or DART may be applicable. This device collects survey data from three voltage inputs and transmits the information to a laptop and receiver located nearby.[75] The system is designed to provide "hands off" operation. Other systems utilize a completely self-contained data logger for electrical resistance type probes. The frequency of data collection points determines the frequency of downloading of data. The more frequent the collection of data, the more frequent the data logger must be downloaded.[76]

CHAPTER 11

GUIDES

The guides were developed to assist in the preservation of inter-hull spaces. They are included in this report as Appendices C through F. Each guide was developed from a wide spectrum of reference material. Existing ASTM Guides and Standards which dealt with similar issues were reviewed for applicability and provided excellent examples of content and scope. Recommendations from coating manufacturer representatives and their work practice instructions for coating ship's ballast tanks and voids were reviewed and collated. Shipyard personnel were interviewed and their comments and recommendations for the preservation of ballast tanks and voids were compared to each other and to the recommendations of the coating manufacturers.

Similar to the development of the proposed inter-hull space preservation protocol, the development of the guides attempts to select those attributes from all the references which were concluded to be essential for providing a preservation system with a 20 year service life for the inter-hull space. Cost information and estimating procedures were obtained from two articles which dealt exclusively on coatings and their associated costs.[77,78]

In the development of the inspection guide, it is important to realize that each of the major players views the inspection requirements and results differently. The ship owner is concerned about safety and the costs of out-of-service time, maintenance, and repairs. The level of detail of the inspection depends on whether the material condition assessment is used to plan for routine maintenance of the corrosion protection system, identify major problems which will require immediate corrective action, plan a major upgrade, meet the demands of the classification societies or authorities with interest in the sale or lay up of the vessel or meet other requirements. On the other hand, the authorities and classification societies are primarily interested in safety, strength and loss of strength in structures and sub-structures and the material condition results establish whether the vessel will require special, interim, and/or annual inspections.

However, the research consistently identified that the single most important ingredient for success in attaining a 20 year preservation system rests with the individuals doing the blasting and painting. Even with clear and precise guidance, a durable and excellent paint system, and the best environmental conditions, it is imperative that the blaster and painter understand the importance of their roles in the coating evolution and perform their jobs correctly. Otherwise, the preservation protocol described in Appendices A and B is doomed to fail. It is essential that these two groups of workers are trained properly and are cognizant of their important roles.

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CHAPTER 12

CONCLUSIONS

- The preservation of the inter-hull space is a major concern for all participants, including ship owners, classification societies, coating manufacturers, and shipyards.

- The material condition of the inter-hull space and "consequence analysis" determine which preservation protocol is "most suitable".

- The best corrosion protection system for the inter-hull area combines a sacrificial cathodic protection system with a hard barrier coating system.

- A cathodic protection system can be designed for the inter-hull area in such a way that it is compatible with a coating system.

- A coating preservation protocol for the inter-hull area is provided which is expected to provide a 15 to 20 year service life.

- Metal spray coating systems are not practical for corrosion protection of the inter-hull area due to poor production rates, high cost, specialized equipment, and increased operator training requirements.

- Vapor phase inhibitors are not recommended for the inter-hull area due to the incompatibility of the inhibitors when the inter-hull space is used as a ballast tank.

- The steel substrate of the inter-hull area should be tested to determine the level of chloride contamination. The Bresle Test Kit with an electronic conductivity meter can quickly provide measurements of the chloride contamination of the steel substrate.

- No single tool can perform all edge rounding/radiusing in the inter-hull space. Seven inch or nine inch disc sanders or grinders with 24 grit aluminum oxide abrasive pads are best for straight runs. Smaller high speed die grinders with various attachments (i.e., flame shaped carbide burrs, concave radius deburring head, or conical stone tips) are best for hard to reach areas. Mastics, polysulfides, and an epoxy coating system specifically formulated for edge covering capacity show initial promise as edge protection systems.

- Sensors which measure the change of the substrate's electrical resistivity are recommended for the inter-hull space. Hard wired and wireless systems designed for other uses can be adapted to the inter-hull space.

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CHAPTER 13

PROPOSED STUDIES

Future studies are proposed for the following subjects:

1. Evaluate the feasibility and effectiveness of using alternative methods (mastic, high build epoxies, caulk, etc.) for edge rounding/radiusing .

As described in Section 6.1, edge radiusing is utilized to prevent the pull back of the coating system from the sharp edge. This results in a thinner layer of coating along the edge relative to the remaining flat surfaces. However, cost analysis[42,43] conducted by the U.S. Navy indicate the procedure to round sharp edges by pneumatic grinders is extremely costly and adversely impacts on the number of tanks which can be overhauled during a given availability. Despite this high cost, shipyards[25-34] continue to manually round edges with disc grinders. The need to reduce this cost burden by the shipbuilder or ship repair facility is essential for each to remain competitive and cost efficient. Other industries have also faced the problem to smooth rough surfaces or leading edges, namely the automotive and airline industries. Mastics and caulks, with specially designed application equipment have been used to smooth damaged or rough edges or surfaces. Also, coating manufacturers in response to the need to smooth edges in ballast tanks, have commenced development of a new specialty coating system which demonstrates the ability to retain a high film build on sharp edges. These alternative methods to smooth edges are promising, but laboratory and in-service tests have not been performed.

It is recommended that a test program be developed, approved, and executed to evaluate these alternative methods for edge rounding. The program should identify the most promising alternative methods through product literature search and manufacturer's testing and in-service documentation. Once this selection is made, laboratory screening evaluations is recommended. These evaluations should include accelerated testing of the products in conditions expected in the inter-hull space. Evaluation parameters should include performance (durability, sag resistance, etc.), productivity (ease of application), compatibility with the tank coating system, time to set, surface preparation requirements, and cost. After the laboratory screening tests, in-service tests in a simulated inter-hull space of the most promising products are recommended. In all evaluations, the products should be evaluated against the control of manually rounding edges by disc grinders.

2. Evaluate the feasibility of electrical resistivity monitors as corrosion sensors in the inter-hull spaces of double hull design ships.

Remote sensors, although not currently used, are a feasible option for monitoring the corrosion of inter-hull spaces in double hull ships. Electrical resistivity sensors work in both wet and dry environments, whereas most other types of sensors must remain immersed to function properly. After a literature search on sensors and a survey of companies, there are several companies capable of providing sensors usable for this application. Since no company currently designs sensors for this specific application, each must modify their candidate sensor(s) to suit the application requirements.

It is recommended that a test program be developed, approved, and executed to evaluate the performance of each candidate sensor in a laboratory and in full scale tests. Accelerated laboratory screening evaluations are recommended. These evaluations should include testing of the sensors in conditions expected to be encountered in the inter-hull space, namely alternate immersion service with typical wet and dry time ratios between 80/20 and 20/80. However, the alternate immersion cycles will be an order of magnitude more frequent than what is normally experienced onboard ship. Evaluation parameters should include durability, ease of installation, accuracy, and cost. After the laboratory screening tests, in-service tests in a full scale model of an inter-hull space of the most promising sensors are recommended. For the full scale model evaluations, the sensors should be evaluated using the same parameters as the laboratory screening evaluations.

3. Validate the inter-hull area preservation protocol in double hull design ships.

Validation of the recommended preservation protocol presented in report is a logical follow-up to this project. It is recommended that a test program be developed, approved, and executed to evaluate the recommended preservation protocol against existing preservation practices for the inter-hull space in terms of performance and life cycle cost.

The test program should identify several existing preservation practices for the inter-hull space, and conduct both laboratory screening and in-service testing of the various preservation practices. As in all testing, the performance attributes to evaluate each preservation practice is important. Since Appendix D was developed to assist in the inspection of the coating system of inter-hull spaces, it is recommended the attributes listed in Paragraph V of Figure 1 of Appendix D be used to evaluate the performance of each preservation practice.

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APPENDIX A

SURFACE PREPARATION PROCEDURE

1. SCOPE:

1.1 This procedure outlines the specific steps recommended for the surface preparation of the inter-hull space prior to the application of the coating system.

2. REFERENCES:

a. Visual Standard For Abrasive Blast Cleaned Steel, SSPC-VIS-1
b. ASTM D4417 Method C, Replica Tape Method

FIGURES:

1. Inspection Form for Environmental Readings
2. Inspection Form for Abrasive Blasting

3. REQUIREMENTS:

3.1 It is the responsibility of the user of this work item to establish appropriate safety and health practices to determine the applicability of regulatory limitation prior to use.

3.2 Abrasive blasters shall be certified in accordance with the requirements of the contract.

3.3 Insure that all openings and pipes are blanked and that any electrical equipment (inter-hull space level indicator cables, transmitters, etc.) is protected prior to start of work.

3.4 Install sufficient dehumidification equipment to maintain a relative humidity of 50% or less in the inter-hull space at all times.

3.4.1 All dehumidification equipment shall be activated prior to abrasive blasting and shall remain on continuously throughout the final curing of the topcoat.

3.4.2 Environmental conditions inside the inter-hull space shall be monitored at least every 4 hours for temperature, dew point and relative humidity. The initial reading shall be taken directly prior to the start of blasting. Blasted surfaces shall be maintained at a temperature such that it is 3 degrees C (5 degrees F) or greater above the dew point. The dew point shall be determined from the lowest steel surface temperature in the inter-hull space. Dehumidification equipment shall be operated to maintain ambient relative humidity within the inter-hull space at 50% or below. Results shall be recorded in Figure 1 or other method of permanent record.

3.5 Prior to blasting, remove all surface contaminants (such as sea salts, grease, oil, loose rust, mud, marine growth) with 72.7 kg/cm^2 (1000 psi) minimum fresh water wash down. This shall be followed by an adequate period of time to allow the surface to dry prior to blasting.

3.6 After cleaning, the contractor shall radius all edges, angles, pipe hangers, and foot/hand holds to a minimum radius of 3 mm.

3.6.1 Clean and remove all dirt, grease, oil, moisture, metal filings, and other contaminants after the radiusing operation.

3.7 All weld protrusions, projections, and spikes shall be ground even with the weld profile and all weld spatter shall be removed by grinding.

CHECKPOINT (Edge Radiusing)

The Quality Assurance (QA) inspector or equivalent shall verify that all edges meet the above radius criteria by measuring at least once every 30 m (100 ft) with a prefabricated template. The QA inspector shall verify that welds and weld spatter meet the above requirements.

3.8 Appropriate measures shall be taken to prevent blast material from entering other parts of the vessel.

3.9 Grit blast inter-hull space with approved abrasive blast media conforming to the requirements of the contract. Blast to SSPC-SP10, near white metal blast clean. A near white blast surface SSPC-SP10 is interpreted as follows: The blast cleaned surface, when viewed without magnification, shall be free of all oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign material, except for staining. Staining shall be limited to no more than 5 percent of each square inch of surface area and may consist of light shadows, slight streaks, or minor discoloration caused by stains or rust, stains from mill scale, or stains from previously applied paint. Surfaces shall be visually compared to SSPC-VIS-1 per Reference 2.a.

3.9.1 All personnel entering the inter-hull space (subsequent to radiusing operations) shall wear coveralls, booties, and clean gloves to minimize contamination of the surface to be painted. Entrances to the inter-hull space shall have an area to wipe soles of booties clean.

CHECKPOINT (Surface Profile)

The QA inspector or equivalent shall verify each inter-hull space has been properly grit blasted in accordance with step 3.9. The average surface profile shall be 50 to 100 microns (2 to 4 mils) based on five measurements per 100 m^2 (1000 ft^2). Profile measurements shall be performed using a TESTEX, Inc. replica tape/dial indicator profile measuring system, or equivalent in accordance with Reference 2.b. Individual QA data shall be recorded in Figure

2, replica tapes shall be retained as part of the permanent QA record.

CHECKPOINT (Chloride Contamination)

The QA inspector or equivalent shall perform surface chloride contamination checks on freshly blasted surface using the Bresle Patch Method. Measurements shall be made randomly over the blasted surface, at different locations in the inter-hull space. One measurement per 100 m^2 (1000 ft^2) shall be made. If any direct measurement exceeds 3 $\mu g/cm^2$ of chloride, a high pressure water wash of the surface will be necessary (proceed to step 3.9.2). If all readings are lower than 3 $\mu g/cm^2$ proceed to step 3.9.3.

3.9.2 Perform a high pressure fresh water wash down of all inter-hull space surfaces to remove all contaminants from the blast profile. Water washing pressure shall be maintained between 72.7 and 145.4 kg/cm^2 (1000 and 2500 psi) and shall not contain inhibitors. Water washing shall commence at the top of the inter-hull space, and progress from side to side in a downward fashion. Residual water shall be blown down using clean, dry compressed air. Vacuum equipment can also be used to remove residual water from pockets, recesses and areas where residual water may collect. After residual water is removed from the inter-hull space, the surface shall be left to dry. For this purpose, dryness can be defined as when the color of the blasted steel resembles the original color when it was first blasted (i.e. no dark spots or water streaks.)

3.9.3 Sweep blast remaining areas in the inter-hull space showing evidence of discoloration due to flash rusting to restore near white (SSPC-SP-10) finish over the entire surface. All rounded edges, welds, etc. treated in accordance with paragraph 3.6 shall receive near white finish and surface profile (50 to 100 microns) specified by step 3.9.

3.9.4 After blasting, the contractor shall clean and remove all spent grit blasting media and paint residue from all surfaces in the inter-hull space. When cleaning spent blasting material from the inter-hull space, special attention should be given to horizontal surfaces and the bottom of the inter-hull space where blasting material is likely to collect. This is accomplished with a blow down of the surface with clean, dry compressed air (not to exceed 30 psi) from all surfaces, followed by vacuuming of bulk spent grit. Additional hand sweeping of the surface followed by vacuuming may be necessary after bulk vacuuming.

4. DEVIATION/WAIVER:

4.1 Any deviation to this procedure must be approved by all parties (i.e. shipowner, ship builder, and coating manufacturer representative) and the waiver must be in writing and maintained as part of the permanent record.

Date	Time	Location	Substrate Temp (^0C)	Wet Bulb	Dry Bulb	Percent RH	Dew Point

FIGURE 1 Inspection Form for Environmental Readings

Date:

Location (Level, Frame, Inboard, Outboard, etc.)	Blast Profile	Inspector's Name

FIGURE 2 Inspection Form for Abrasive Blasting

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APPENDIX B

PAINTING PROCEDURE

1. SCOPE:

1.1 This procedure outlines the specific steps recommended for the application of the coating system in the inter-hull space.

2. REFERENCES:

None.

FIGURES:

1. Inspection Form for Environmental Readings
2. Inspection Form for Inter-Hull Space Preservation
3. Inspection Form for Dry Film Thickness Measurements

3. REQUIREMENTS:

3.1 It is the responsibility of the user of this work item to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

3.2 Install sufficient dehumidification equipment to maintain a relative humidity of 50% or less in the inter-hull space at all times.

3.2.1 All dehumidification equipment shall be activated prior to abrasive blasting and shall remain on continuously throughout the final curing of the topcoat.

3.2.2 Environmental conditions inside the inter-hull space shall be monitored at least every 4 hours for temperature, dew point and relative humidity. The initial reading shall be taken directly prior to the start of blasting. Surfaces to be painted shall be maintained at a temperature that it is 3 degrees C (5 degrees F) or greater above the dew point. The dew point shall be determined from the lowest steel surface temperature of the inter-hull space. Dehumidification equipment shall be operated to maintain relative humidity within the inter-hull space at 50% or below. The inter-hull space coatings shall be applied only when temperatures in the inter-hull space meet the requirements of the coating manufacturer's instructions. Surface temperature requirements shall be as specified by the coating manufacturer's instructions but shall not conflict with those stated above. Results shall be entered on Figure 1 or other method of permanent record.

CHECKPOINT (Surface Temperature And Dew Point)

The contractor shall complete Figure 1 and verify surface temperatures and dew point requirements are within the limits specified above.

3.3 Coatings used in the inter-hull space shall be a high solids, low Volatile Organic Compound (VOC) epoxy coating system.

3.4 All personnel entering the inter-hull space shall wear coveralls, disposable booties, and clean gloves to minimize contamination of the surfaces to be painted, as well as to protect the primed surfaces. Entrances to the inter-hull space shall have an area to wipe soles of booties clean.

3.5 The contractor shall paint the inter-hull space in accordance with the requirements of this document and the coating manufacturer's instructions. In the event of a conflict between this document and the coating manufacturer's instructions, the coating manufacturer and the contractor shall mutually resolve the conflict. Figures 1 and 2 shall be used to record the inter-hull space and paint conditions prior to paint application. Appropriate steps must be taken to consider the requirements for pot life, thinning, dry times between coats (minimum and maximum), induction time, and time for full cure of the coating system.

3.6 Apply the first or prime coat of the coating system in accordance with the coating manufacturer's instructions and this document. Allow the first full coat to cure in accordance with the coating manufacturer's instructions. A prime coat that can be indented with the fingernail shall be allowed additional time to dry.

CHECKPOINT (Primer Dry Film Thickness (DFT))

Thickness measurements are required at five random areas per every 100 m^2 (1000 ft^2) of painted surface area. DFT measurements shall be recorded on Figure 3. Measurements on edges, corners and welds shall be taken for reference purposes only. There shall be NO uncoated areas.

3.7 Stripe coat all edges, weld seams, foot/hand holds, and other mounting hardware (non-flat surface) of the inter-hull space. Stripe coating shall be performed using the recommended method of the coating manufacturer. The stripe coat shall consist of a contrasting color to the first or prime coat. Stripe coating shall encompass all edges as well as at least one-inch border outside each edge. The stripe coat thickness should be as prescribed by the coating manufacturer instructions. The stripe shall be neat in appearance, minimizing extra thicknesses applied to edges, as well as streaks and drops of paint. Paint sags and drips shall be brushed out immediately to prevent curing of excessive thicknesses.

CHECKPOINT (Stripe Coat Application)

A visual inspection of stripe coat quality and completeness shall be performed prior to the application of the next stripe coat. Denote completion of this check point on Figure 2.

3.8 Apply a second stripe coat of the coating system of a contrasting color to the first stripe coat, but not a light color to all edges, weld seams, foot/hand holds, and other mounting hardware. Stripe coating shall be applied in accordance with section 3.7 of this procedure.

CHECKPOINT (Stripe Coat Application)

A visual inspection of stripe coat quality and completeness shall be performed prior to the application of the top coat. Denote completion of this check point on Figure 2.

3.9 If the top coat interval exceeds the maximum number of days from primer application as recommended by the coating manufacturer's instructions, follow the coating manufacturer's instructions in applying a mist or tie coat to the prime coat. After a dry-to-touch-time as specified by the coating manufacturer's instructions, spray apply the light colored top coat to produce a Wet Film Thickness (WFT) in accordance with the coating manufacturer's instructions and to meet the DFT requirements of the coating manufacturer. Random WFT measurements shall be taken during application to ensure the specified DFT is obtained.

3.10 If a fingernail, or the base of the DFT gage can leave an impression in the coating, it is still not ready for final measurements. Perform final DFT measurements to ensure a total system coverage over non-striped areas. Striped areas should naturally have a greater total DFT.

CHECKPOINT (Final DFT)

Final paint thickness measurements are required at five random areas per every 100 m^2 (1000 ft^2) of coated surface area. DFT measurements shall be recorded on Figure 3. There shall be NO uncoated areas.

3.10.1 Areas not having sufficient build of paint shall be recoated with the light colored top coat of the coating system until sufficient final DFT is achieved. The coating manufacturer's recommended dry time prior to recoat after application of the top coat must be observed.

3.11 Any areas that are damaged due to weld repair, removing of staging, or other means shall be prepared to SSPC-SP 11, power tool clean to bare metal finish, using a profile producing mechanical tool or combination of tools such as a rotating cutter hub, flapper wheel, roto-peen, or pro-scaler type device. Circular disc sanders and needle guns ARE NOT acceptable tools for use in surface preparation in immersion areas when used alone. The intact coating around the repaired surface shall be "feathered" to create a smooth transition between coated and cleaned areas. Hand brush two coats of the coating system to the bare metal areas. Final system DFT in these areas shall be in accordance with the coating manufacturer's recommendations.

CHECKPOINT (Holiday Check)

The contractor shall perform holiday checks on the final tank coating, using either a low voltage wet sponge or high voltage spark tester depending upon the expected final DFT of the coating system. Any holiday (defects to bare metal) found will be marked by the inspector, ground out to a 1" diameter and touched up as in Section 3.11.

3.12 Allow for proper drying time as per the coating manufacturer's instructions after the application of the final coat (including damaged touch-up areas) prior to placing the inter-hull space back in service. Dehumidification equipment shall be used to maintain these environmental conditions from abrasive blasting through final cure of the topcoat.

4. DEVIATION/WAIVER:

4.1 Any deviation to this procedure must be approved by all parties (i.e., ship owner, ship builder, coating manufacturer) and the waiver must be in writing and maintained as part of the permanent records.

Date	Time	Location	Substrate Temp (°C)	Wet Bulb	Dry Bulb	Percent RH	Dew Point

FIGURE 1 Inspection Form for Environmental Readings

Inter-Hull Space Description	Primer Coat	First Stripe Coat	Second Stripe Coat	Top Coat
Date and Time				
Elcometer Serial Number				
Near White Surface Preparation				
Dry Bulb Temperature (Ambient)				
Wet Bulb Temperature				
Dew Point				
Surface Temperature				
Paint Temperature				
Epoxy Paint Used				
Batch Number				
Ambient Temperature of Job Site				
Ambient Temperature of Paint Mixing Area				
Name of Painter				
Name of Pump Operator				
Supervisor's Sign Off				

First Stripe Coat Checkpoint: SAT UNSAT

Comments:____

Second Stripe Coat Checkpoint: SAT UNSAT

Comments:____

FIGURE 2 Inspection Form for Inter-Hull Space Preservation

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

Reading Number	Total DFT Reading (Mil)	Coat No. and Approx Location
Average		

This sheet may be duplicated for additional DFT readings.

FIGURE 3 Inspection Form for Dry Film Thickness Measurements

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APPENDIX C

Standard Guide for Evaluating Whether to Repair or Replace the Coating of Inter-Hull Spaces

1. Scope

1.1 This guide provides general guidelines for a detailed assessment of the condition of coatings in the inter-hull spaces of double hulled ships to assist in making the determination to repair or replace the coatings.

1.2 This guide does not address the problem of determining the structural condition of a steel substrate. It provides procedures to determine the amount of the coating deterioration, but not the severity, condition, nor cause of the deterioration.

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces

D660 Test Method for Evaluating Degree of Checking of Exterior Paints

D714 Test Method for Evaluating Degree of Blistering of Paints

D1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base

D3359 Test Methods for Measuring Adhesion by Tape Test

D3363 Test Method for Film Hardness by Pencil Test

D4138 Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Methods

D4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

F1131 Practice for Inspecting the Coating System of a Ship's Tanks and Voids

G46 Practice for Examination and Evaluation of Pitting Corrosion

2.2 ANSI/API Standards:

653 Tank Inspection, Repair, Alteration, and Reconstruction

3. Summary of Practice

3.1 This practice for assessing the condition of coatings consists of identifying three representative areas of an inter-hull space; establishing for each, commonly occurring modes of coating deterioration using visual standards; simple evaluation tools; and using a flow chart to determine whether to repair, replace, or not to re-preserve an inter-hull space coating. A form for recording the results of the assessment procedure, Figure 1, is provided.

4. Preparation for Inspection

4.1 This guide describes the duties of the evaluator and discusses the evaluation methods, both visual and instrumental, that can be used to determine the condition of the coatings.

4.2 The evaluator must be able to perform the following tasks:

4.2.1 Calibrate and use a magnetic gage to measure Dry Film Thickness (DFT).

4.2.2 Calibrate and use eddy current thickness gages to measure DFT.

4.2.3 Use a camera properly. Good illustrative photographs are of great importance as additions to the report. A camera with auto focus, telephoto lens, date/time function and integrated flash can be used in most types of inspections. It is important for the light source to reproduce colors correctly.

4.2.4 Recognize the various types of corrosion and forms of coating failure (pitting, flaking, etc.).

4.2.5 Convert visual findings into accurate percent of corrosion or deterioration of the coating system.

4.3 All safety requirements and the inspection plan must have been fully discussed and approved by all parties involved (i.e., ship owner, shipyard, coating manufacturer).

5. Inspection

5.1 All coatings damaged during the inspection shall be properly repaired by spot cleaning, touching up with primer, and finishing all surfaces of disturbed areas.

5.2 Visual observation is the most important part of the evaluation process. Adequate lighting by either hand-held flashlights or portable lighting shall be provided to the inspector. The surface to be inspected shall be easily accessible to the inspector. If the inspection area is completely obscured and cannot be inspected, denote so on the inspection form.

6. Procedure

6.1 The following paragraphs coincide with the individual sections of Figure 1, Inspection Form, Figure 1, to aid in the proper completion of Figure 1.

6.1.1 *Ship and Hull Number* - Indicate the name of vessel and type of vessel and hull number.

6.1.2 *Date* - Date(s) of evaluation.

6.1.3 *Location* - City and country of shipyard location.

6.1.4 *Inspector's Name* - Printed name of the evaluator.

6.1.5 *Inspector's Signature* - Signature of evaluator.

6.1.6 *Tank Number* - Indicate the ship area evaluated by tank number. Where appropriate, frame numbers and/or ship levels shall be included.

6.1.7 *Last Previous Coating System* - Indicate the coating system applied by denoting the surface preparation process employed; year of application; and designation by name of coating system used, listing the primer, all mid-coats, and topcoat.

6.1.8 *Photographs* - For each inspection area, a photograph of the entire area is required. If the area is too large to capture in one photograph, the area should be divided into equal sized segments and each segment should be photographed. Each photograph should be marked with the area number, ship name, and date. Also, a size scale should be captured in each photograph. This size scale is a reference standard that would be used to determine the approximate size of the photographed area.

6.1.9 *Inspection Area* - The inter-hull area is segmented into four representative areas. The four representative areas shall be the 'outer boundary structure' (shell and deck), 'inner boundary structure' (longitudinal bulkhead, tank top, centerline girder), 'forward and aft boundary structure' (bulkheads) and 'interior non-boundary structure' (all others).

6.1.10 *Inspection Area Percentage* - Determine the approximate percentage of the total inter-hull area which represents the area being inspected. Note, for each tank, the total area for the bulkheads, overhead, and deck shall equal 100 percent.

6.1.11 *Inspection Area Obscured* - If the inspection area is significantly obscured and cannot be adequately inspected, circle "YES". If the inspection area is not significantly obscured, circle "NO".

6.1.12 *Corrosion*

6.1.12.1 *General Corrosion*

6.1.12.1.1 *Overall Extent of Failure* - Using the overall extent diagrams enter the number of the diagram that most closely approximates the overall extent of general corrosion per the procedures outlined in Standard Practice F1131. If there is no general corrosion in this inspection area, enter the number "0" (zero) and leave the next line (extent within affected area) blank.

6.1.12.1.2 *Extent Within Affected Area* - Using the extent diagram within the affected area enter the letter of the diagram that most closely approximates the extent of general corrosion within the affected area per the procedures outline in Standard Practice F1131. For no corrosion, denote by letter "A" and move to paragraph 6.1.12.2.

6.1.12.1.3 *Scattered or Concentrated* - Based upon the area of inspection and the overall extent of general corrosion, determine if the corrosion is scattered or concentrated. Circle "YES" next to the appropriate determination.

6.1.12.1.4 *Degree of Rust* - Determine the percentage of the area rusted by following the procedure outlined in Standard Test Method D610.

6.1.12.2 *Pitting* - Pitting is the localized corrosion of a metal surface, confined to a point or small area, that takes the form of cavities. If no pitting is present, denote in the line next to size by entering "NONE" and move to paragraph 6.1.13.

6.1.12.2.1 *Size, Shape and Density* - Determine the size, shape and density of pitting by following the procedure outlined in Standard Practice G46.

6.1.12.2.2 *Depth* - The pit depth of the worst pit should be measured as outlined in ANSI/API 653. Pit depths of 50% or more of the original metal thickness should be repaired.

6.1.13 *Coating Breakdown*

6.1.13.1 *Blistering* - A phenomenon peculiar to painted surfaces is the formation of blisters at the location of some system weakness. If no blistering is noted in the inspection area, denote by entering "NONE" on the lines next to size and density and move to paragraph 6.1.13.2.

6.1.13.1.1 *Size and Density* - Rate the size and density of the blister by using Test Method D714 by entering the number that most closely approximates the largest blister and the highest blister density in the inspection area, respectively.

6.1.13.2 *Delamination* - Delamination is characterized by detachment of the coating from the substrate or by a layer separation between the coats of paint. If no delamination is noted in the inspection area, denote by entering "NONE" on the line next to level and move to paragraph 6.1.13.3.

6.1.13.2.1 *Level* - Determine the type of delamination observed in the inspection area by denoting which level of delamination illustrated in Standard Practice F1131 most closely resembles the delamination in the inspection area.

6.1.13.3 *Checking* - Checking is the phenomenon manifested in coatings by slight breaks in the coating that do not penetrate through the last applied coating. If no checking is noted in the inspection area, denote by entering "NONE" on the line next to degree and type and move to paragraph 6.1.13.4.

6.1.13.3.1 *Degree and Type* - Determine the degree and type of checking by comparing the checking of the coating system with the diagrams illustrated in Test Method D660 and select the degree and type of checking which most closely approximates the checking noted in the inspection area.

6.1.13.4 *Flaking* - Determine the extent of flaking within the affected area by using Standard Practice F1131 by entering the letter of the diagram that most closely approximates the extent of flaking within the affected area. If no flaking is present, denote in the line next to flaking by entering "NONE" and move to paragraph 6.1.14.

6.1.14 *Mechanical Damage* - Determine the overall extent of mechanical damage by using Standard Practice F1131 by entering the number of the diagram that most closely approximates the overall extent of corrosion due to mechanical damage. If there is no corrosion due to mechanical damage in this inspection area, enter the number "0" (zero) and move to paragraph 6.1.15.

6.1.14.1 *Extent Within Affected Area* - Determine the extent within the affected area of corrosion due to mechanical damage by using Standard Practice F1131 by entering the letter of the diagram that most closely approximates the extent of corrosion due to mechanical damage within the affected area.

6.1.14.2 *Type of Damage* - If corrosion due to mechanical damage has occurred, use the photographic examples of Standard Practice F1131 to identify the type of mechanical damage that has occurred. On the inspection form, circle the type of damage (scraping/impact or internal welds/burn marks) that has occurred.

6.1.15 *Tests*

6.1.15.1 *Adhesion* - Adhesion is the coating's ability to remain on the substrate. Record the test method used from either Test Methods D3359 or Test Method D4541 and the equipment used to obtain the adhesion measurements of the coatings. Enter the five measurements taken for every 100 square meters within the inspection area.

6.1.15.2 *Dry Film Thickness* - Measurements of dry film thickness are of great importance because the protection of the substrate is directly related to the thickness of the coating. Coating thicknesses can be determined by either Test Methods D1186, Test Method 1400, or Test Method D4138 depending on the substrate material and whether destructive or non-destructive tests are to be used. If destructive measurements are performed, repair damaged areas by spot cleaning, touching up with primer, and finishing all surfaces of disturbed areas. Five measurements shall be randomly taken every 100 square meters within the inspection area.

6.1.15.3 *Hardness* - Determine the coating film hardness by performing the procedure described in Test Method D3363. Five measurements shall be randomly taken every 100 square meters within the inspection area.

6.1.16 *Remarks* - Indicate specific and overall comments which the inspector feels will assist the ship owner and operator in assessing the condition of the coating system and ultimately, whether the coating system needs to be repaired, replaced, or left as is.

6.2 The following paragraphs coincide with the individual sections of Figure 2, Figure of Merit Calculation, to aid in the proper completion of Figure 2. Figure 2 shall be completed for each of the three inspection areas of a tank.

6.2.1 *Rating Scale* - For every characteristic taken above in paragraphs 6.1.12 to 6.1.15, determine a rating scale for the severity of the coating failure from 0 to 10, where "0" denotes no failure and "10" denotes complete failure in the inspection area. As a guide, use the overall extent of failure diagrams of Standard Practice F1131. These diagrams depict 11 different levels of failure which the inspector may use as a reference to rate the level of failure of each coating failure characteristic. The rating scale for DFT and hardness shall be determined based upon the findings listed in Figure 1. For low values of each, the rating scale should be greater than 5. For high values of each, the rating scale should be lower than 5.

6.2.2 *Magnitude Multiple* - Each coating failure characteristic is provided with a pre-determined magnitude multiple. The higher the magnitude multiple, the more significant the failure mode is to representing coating failure. The total of all magnitude multiples is 1.0. The magnitude multiple for general corrosion is 0.2 while all other coating failure characteristics have a magnitude multiple of 0.1.

6.2.3 *Figure of Merit (FOM)* - The figure of merit is a weighted value of a coating's failure characteristic. The higher the figure of merit for a particular failure characteristic, the more severe the failure is for that characteristic. Calculate the figure of merit for each coating failure characteristic by multiplying the number in the rating scale column (0 to 10) with the number in the magnitude column (0.1 or 0.2). The value for the figure of merit should range between 0.0 to 2.0.

6.2.4 *Total Figure of Merit For Inspection Area* - The total of all coating failure characteristic figure of merits represents the weighted total value of all failures within the inspection area. Add the figure of merit values for each failure characteristic in Figure 2 to obtain this value. The higher this value, the more severe the failure is for all characteristics of failure within the inspection area. The highest value for the figure of merit total is 10.0.

6.2.5 *Total Weighted Figure of Merit For Inspection Area* - The weighted figure of merit for the inspection area is determined by multiplying the inspection area percentage by the figure of merit total for the inspection area. Write in this calculated value on the blank line provided in Figure 2.

6.2.6 *Figure of Merit Total For Tank* - The total of all weighted figure of merits for the three inspection areas in the tank (bulkheads, overhead, and floor) represents the weighted total value of all failures within the tank. Write in this calculated value in Figure 2 for all three inspection areas of each tank. The higher this value, the more severe the failure is for all characteristics of failure within the tank. The highest value for the total tank figure of merit is 10.0.

7. Report

7.1 Prepare an evaluation report. Figures 1 and 2 shall be completely filled in for each tank inspected.

8. Flow Chart

8.1 *Flow Chart* - A flow chart is included as Figure 3 to assist in the decision making for repairing, replacing, or leaving the coating system as is for each inter-hull space. This flow chart is based upon the current definition by the International Association of Classification Societies (IACS) for coating conditions and other considerations.

8.2 *IACS Ratings*

8.2.1 *IACS Good Condition* - When there is only minor spot rusting.

8.2.2 *IACS Fair Condition* - When there is local breakdown of coating at edges of stiffeners and weld connections and/or light rusting over 20 percent or more of areas under consideration, but less than as defined for poor condition.

8.2.3 *IACS Poor Condition* - When there is general breakdown of coating over 20 percent or more areas, or hard scale at 10 percent or more of areas under consideration.

8.3 *Water Ballast Tanks* - An important decision point in the flow chart is whether the water ballast tank is a double bottom or not. This distinction is made because for ships over five years old, a "POOR" condition rated water ballast tank is required to be examined annually if the tank is other than a double bottom tank. For double bottom water ballast tanks, where the coating is found to be in "POOR" condition, the tank may be examined during each annual survey.

8.4 *Scattered Versus Concentrated Corrosion* - The repair of corrosion concentrated in a particular area of an inspection area is much easier and less costly to complete than the repair of the same amount of corrosion scattered throughout the inspection area or throughout the tank. Concentrated corrosion in most cases favors either repair procedures or leaving the coating system as is, while scattered corrosion favors the replacement of the tank coating system.

8.5 *Consequence Analysis* - An important parameter in the decision flow chart is the requirement to conduct a consequence analysis. This analysis considers several questions whose answers will assist the ship owner in determining the most suitable course of action to take in preserving the inter-hull space of the vessel.

8.6 *Potential Benefits for Replacing a Coating System* - There are distinct advantages for replacing a coating system compared to either repairing or leaving the coating system as is. The potential benefits include life extension, increased second hand value, increased earning rate, reduced off-line for future repairs, longer period before further repair, less future renewal of steel work and/or coatings, reduced insurance claims and premiums, improved cosmetic appearance, and improved ability to conduct future surveys.

9. Keywords

9.1 assessment; corrosion; coating; inter-hull; repair; replacement; inspection

Condition Assessment

Ship and Hull Number ______________________________
Date ______________________________
Location ______________________________
Inspector's Name ______________________________
Inspector's Signature ______________________________
Tank Number ______________________________

Last Previous Coating System

Surface
Preparation ______________________
Year Applied ______________________
Primer ______________________
Midcoat ______________________
Midcoat ______________________
Topcoat ______________________

I. Photographs
- A. Entire Area
- B. Close-Up of All Damage

II. Inspection Area .... ____________

III. Inspection Area Percentage .... ____________

IV. Inspection Area Obscured? Yes No

V. Ratings
- A. Corrosion
  - 1. General Corrosion
    - a. Overall Extent of Failure .... ____________
    - b. Extent Within Affected Area .... ____________
    - c. Scattered .... Yes
    - d. Concentrated .... Yes
    - e. Degree of Rust .... ____________
  - 2. Pitting
    - a. Size .... ____________
    - b. Shape .... ____________
    - c. Density .... ____________
    - d. Depth .... ____________

B. Coating Breakdown
1. Blistering
a. Size .... ________________
b. Density .... ________________

2. Delamination
a. Level .... ________________

3. Checking
a. Degree .... ________________
b. Type .... ________________

4. Flaking .... ________________

C. Mechanical Damage
1. Overall Extent of Failure .... ________________
2. Extent Within Affected Area .... ________________
3. Type of Damage .... Scraping/Impact   Welds/Burns

D. Tests
1. Adhesion
a. Test Method .... ________________
b. Equipment .... ________________
c. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

2. Dry Film Thickness
a. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

3. Hardness

a. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

V. Remarks

____

____

____

____

____

FIGURE 1 Inspection Form

Tank ______________________________
Inspection Area ______________________

Failure Characteristic	Rating Scale	Magnitude Multiple	Figure of Merit
General Corrosion		0.2	
Pitting		0.1	
Blistering		0.1	
Delamination		0.1	
Checking		0.1	
Flaking		0.1	
Adhesion		0.1	
Dry Film Thickness		0.1	
Hardness		0.1	

TOTAL FIGURE OF MERIT = ___________
FOR INSPECTION AREA

TOTAL WEIGHTED FIGURE = ___________
OF MERIT FOR INSPECTION
AREA

TOTAL FIGURE OF MERIT = ___________
FOR TANK

FIGURE 2 Figure of Merit Calculation

REPAIR PROCEDURE FLOW CHART

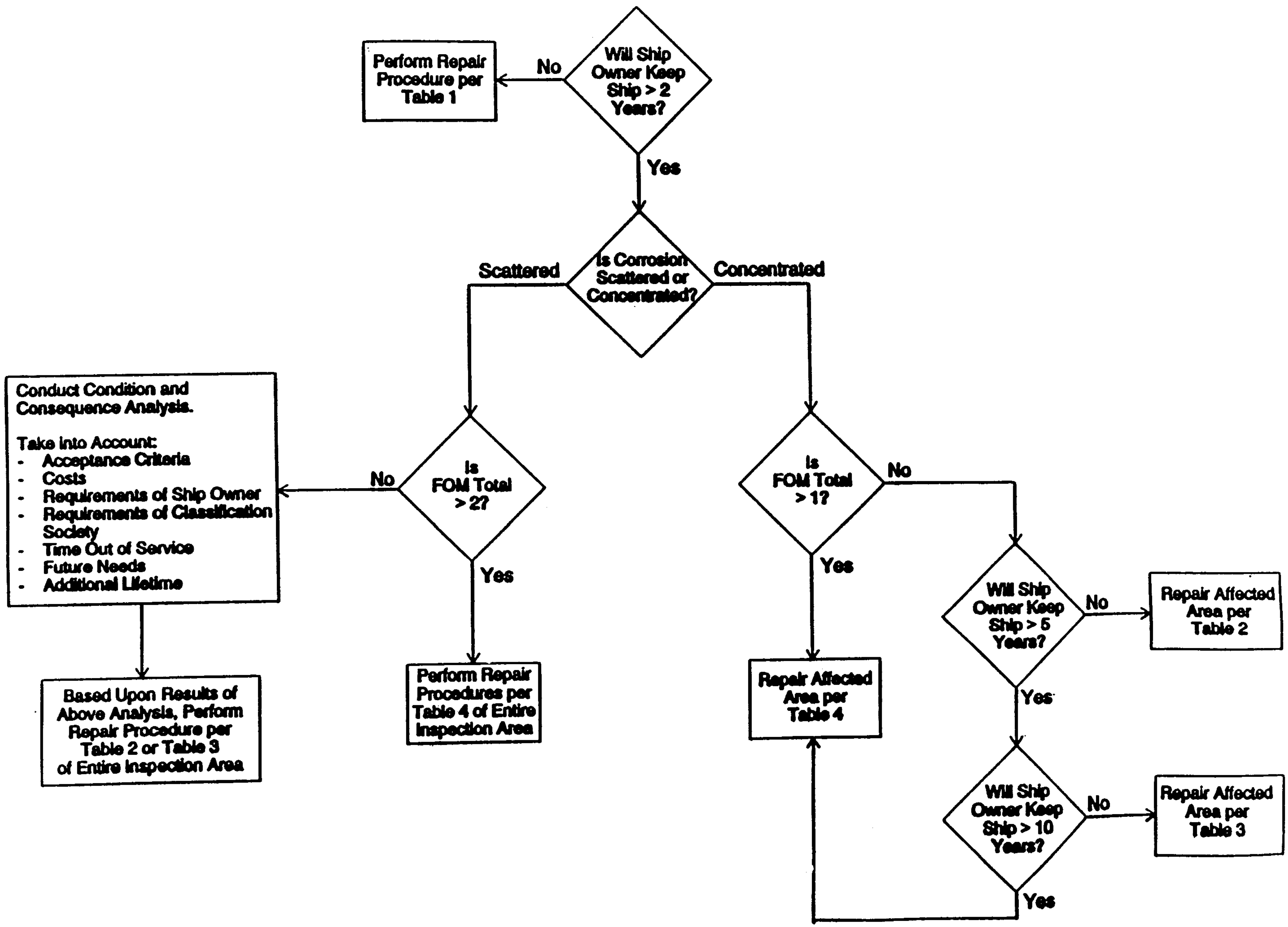

TABLE 1 Preservation System for Expected Lifetime of Less Than 2 Years

- No maintenance is recommended for limited coating damage
- For instances of major coating damage
  -- Remove mud, oil, grease
  -- High pressure fresh water wash
  -- Remove water
  -- Prepare surface to SSPC-SP 7, Brush Off Blast
  -- Apply epoxy mastic (surface tolerant)
  -- Two coats each at 6 mils DFT

TABLE 2 Preservation System for Expected Lifetime of 2 to 5 Years

- Remove mud, oil, grease
- Fresh water wash
- Remove water
- High pressure hydroblast or abrasive blast
- Dry
- Climate control
- Prepare surface to SSPC-SP 6, Commercial Blast Clean
- Apply epoxy mastic (surface tolerant)
- Two coats each at 6 mils DFT with an intermediate coat

TABLE 3 Preservation System for Expected Lifetime of 5 to 10 Years

- Remove mud, oil, grease
- Fresh water wash
- Remove water
- Dry by means of dehumidification
- Climate control
- Blast clean damaged areas to SSPC-SP 10, Near White Metal Blast
- Coat with high build epoxy or epoxy mastic
- Two coats each at 6 mils DFT with two intermediate stripe coats

TABLE 4 Preservation System for Expected Lifetime of 15 to 20 Years

- Remove mud, oil, grease
- Fresh water wash
- Remove water
- Dry by means of dehumidification
- Climate control
- Round all edges
- Smooth all welds
- Blast clean all areas to SSPC-SP 10, Near White Metal Blast
- Check for surface contamination
- Coat with high build epoxy
- Two coats each at 8 to 10 mils DFT with two intermediate stripe coats

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APPENDIX D

Standard Guide for the Inspection of the Coating of Inter-Hull Spaces

1. Scope

1.1 This guide describes a standard procedure for inspecting the coating system in the inter-hull spaces of double hulled ships. Included are the frequency which these inspections should occur, the scope of each inspection, referenced documents which rate the condition of the coating for various characteristics, and an inspection form to record the inspection data.

1.2 This guide is intended for use only by an experienced marine coating inspector.

1.3 It is intended that this guide be utilized to coordinate the inspection between the ship owner and operators.

1.4 This guide does not establish accept/reject criteria for coating inspection nor does it address methods of repairing existing deficiencies. It does, however, provide a means of identifying them.

1.5 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces

D660 Test Method for Evaluating Degree of Checking of Exterior Paints

D714 Test Method for Evaluating Degree of Blistering of Paints

D1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base

D1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base

D3359 Test Method for Measuring Adhesion by Tape Test

D3363 Test Method for Film Hardness by Pencil Test

D4138 Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Methods

D4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

F1131 Practice for Inspecting the Coating System of a Ship's Tanks and Voids

G46 Practice for Examination and Evaluation of Pitting Corrosion

2.2 ANSI/API Standards:

653 Tank Inspection, Repair, Alteration, and Reconstruction

3. Significance and Use

3.1 This guide is intended as a reference for those concerned with the inspection of the coating systems in inter-hull spaces of double hull ships. An inspection form is provided as Figure 1.

4. Preparation for Inspection

4.1 The guide describes the duties of the inspector and discusses inspection methods, both visual and instrumental, that can be used to determine the condition of the coatings.

4.2 The inspector must be able to perform the following tasks:

4.2.1 Calibrate and use a magnetic gage to measure Dry Film Thickness (DFT).

4.2.2 Calibrate and use eddy current thickness gages to measure DFT.

4.2.3 Use a camera properly. Good illustrative photographs are of great importance as additions to the report. A camera with auto focus, telephoto lens, date/time function and integrated flash can be used in most types of inspections. It is important for the light source to reproduce colors correctly.

4.2.4 Recognize the various types of corrosion and forms of paint failures (blistering, delamination, etc.).

4.3 All safety requirements and the inspection plan must have been fully discussed and approved by all parties involved.

5. Inspection

5.1 In all cases, inspection of the coating system shall be limited to as small an area necessary for the inspector to obtain a representative assessment of the coating in that specific area. Each inter-hull space shall be segmented into four representative areas. The four representative areas shall be the 'outer boundary structure' (shell and deck), 'inner boundary structure' (longitudinal bulkhead, tank top, centerline girder), 'fore and aft boundary structure' (bulkheads), and 'interior non-boundary structure' (all others). All coatings damaged during the inspection shall be properly repaired by spot cleaning, touching up with primer, and finishing all surfaces of disturbed areas.

5.2 Visual observation is the most important part of the inspection process. Adequate lighting by either hand-held flashlights or portable lighting shall be provided to the inspector. The surface to be inspected shall be easily accessible to the inspector. If the inspection area is completely obscured and cannot be inspected, denote so on the inspection form.

6. Report

6.1 The following paragraphs coincide with the individual sections of the sample "Condition Assessment" inspection form, Figure 1, to aid in their proper completion.

6.1.1 Ship *and Hull Number* - Indicate the name and type of vessel and hull number.

6.1.2 Date - Date(s) of inspection.

6.1.3 *Location* - City and country of ship during the inspection.

6.1.4 Inspector*'s Name* - Printed name of the inspector.

6.1.5 *Inspector's Signature* - Signature of inspector.

6.1.6 Tank Number - Indicate the ship area inspected by tank number. Where appropriate, frame numbers and/or ship levels shall be included.

6.1.7 Original Coating System - Indicate the original coating system applied by denoting the surface preparation process employed; year of application; and designation by name of coating system used, listing the primer, all mid-coats, and topcoat.

6.1.8 1st Maintenance Coating System - Similar to instruction 6.1.7, but list, if applicable, all the information applicable to the first maintenance coating system.

6.1.9 2nd Maintenance Coating System - Similar to instruction 6.1.7, but list, if applicable, all the information applicable to the second maintenance coating system.

6.1.10 *Photographs* - For each inspection area, a photograph of the entire area is required. If the area is too large to capture in one photograph, the area should be divided into equal sized segments and each segment should be photographed. An individual close-up photograph of each damaged section in the inspection area is required. Each photograph should be marked with the area number, ship name, and date. Also, a size and color scale should be captured in each photograph. This size scale is a reference standard that would be used to determine the approximate size of the photographed area. The color scale is a reference standard for any colors which appear in the photograph.

6.1.11 *Inspection Area* - The inter-hull area is segmented into four inspection areas as referenced above. Denote on the condition assessment form if the areas inspected are bulkheads, the overhead, or the deck/floor.

6.1.12 *Inspection Area Percentage* - Determine an approximate percentage of the total inter-hull area which represents the area being inspected. Note, for each tank, the total area for the bulkheads, overhead, and deck shall equal 100 percent.

6.1.13 *Inspection Area Obscured* - If the inspection area is completely obscured and cannot be inspected, circle "YES". If the inspection area is not completely obscured, circle "NO".

6.1.14 *Corrosion*

6.1.14.1 *General Corrosion* - Using the overall extent diagrams enter the number of the diagram that most closely approximates the overall extent of general corrosion per the procedures outlined in Standard Practice F1131. If there is no general corrosion in this inspection area, enter the number "0" (zero) and leave the next line (extent within affected area) blank.

6.1.14.1.1 *Extent Within Affected Area* - Using the extent within affected area diagrams enter the letter of the diagram that most closely approximates the extent of general corrosion within the affected area. Remember, if the overall extent of failure line above is marked with a "0" (zero), leave the extent within affected area line blank.

6.1.14.1.2 *Scattered or Concentrated* - Based upon the area of inspection and the overall extent of general corrosion determine if the corrosion is scattered or concentrated. Circle "YES" next to the appropriate determination.

6.1.14.1.3 *Degree of Rust* - Determine the percentage of the area rusted by following the procedure outlined in Standard Test Method D610.

6.1.14.2 Pitting - Pitting is the localized corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

6.1.14.2.1 *Size* - Determine the average size of pitting by entering the letter-number which most closely approximates the sizes illustrated in Standard Practice G46.

6.1.14.2.2 *Shape* - A visual examination of the metal surface may show a round, elongated, or irregular opening, but it seldom provides an accurate indication of corrosion beneath the surface. Therefore, it may be necessary to cross section the pit to see its actual shape and to determine its true depth. Determine the shape of the majority of the pits by writing in the description of pit shapes denoted in Standard Practice G46.

6.1.14.2.3 *Density* - Determine the density of pitting by entering the letter-number which most closely approximates the density illustrated in Standard Practice G46.

6.1.14.2.4 *Depth* - The pit depth of the worst pit should be measured as outlined in ANSI/API 653. Pit depths of 50% or more of the original metal thickness should be repaired.

6.1.15 *Coating Breakdown*

6.1.15.1 Blistering - A phenomenon peculiar to painted surfaces is the formation of blisters at the location of some system weakness.

6.1.15.1.1 *Overall Extent of Failure* - Determine the overall extent of blistering failure by using Standard Practice F1131 by entering the number of the diagram that most closely approximates the overall extent of blistering. If there is no blistering in this inspection area, enter the number "0" (zero) and move to paragraph 6.1.15.2.

6.1.15.1.2 *Extent Within Affected Area* - Determine the extent within the affected area of blistering failure by using Standard Practice F1131 and enter the letter of the diagram that most closely approximates the extent of blistering within the affected area.

6.1.15.1.3 *Size* - Rate the size of the blister by using Test Method D714 by entering the number that most closely approximates the largest blister in the inspection area.

6.1.15.1.4 *Density* - Rate the density of the blisters by using Test Method D714 by entering the number that most closely approximates the highest blister density in the inspection area.

6.1.15.2 *Delamination* - Delamination is characterized by detachment of the coating from the substrate or by a layer separation between the coats of paint.

6.1.15.2.1 *Overall Extent of Failure* - Determine the overall extent of delamination by using Standard Practice F1131 and enter the number of the diagram that most closely approximates the overall extent of delamination. If there is no delamination in this inspection area, enter the number "0" (zero) and move to paragraph 6.1.15.3.

6.1.15.2.2 *Extent Within Affected Area* - Determine the extent within the affected area of delamination by using Standard Practice F1131 and enter the letter of the diagram that most closely approximates the extent of delamination within the affected area.

6.1.15.2.3 *Topcoat* - Mark an "X" on the blank line beside Topcoat if topcoat delamination has occurred. Topcoat delamination has occurred if only the outermost coating has separated from all undercoats. A diagram of topcoat delamination is illustrated in Standard Practice F1131.

6.1.15.2.4 *Within Repair System* - Mark an "X" on the blank line beside Within Repair System if delamination has occurred between layers of the repair system excluding delamination between the topcoat and the outermost undercoat. This is topcoat delamination. The repair system is defined as any coating system that is applied on top of the original coating system. If the original coating system has not been overcoated, delamination within the repair system is not possible. A diagram of delamination within repair system is illustrated in Standard Practice F1131.

6.1.15.2.5 *Between Original/Repair* - Mark an "X" on the blank line beside Between Original/Repair if delamination has occurred between the outermost coat of the original coating system and the innermost coat of the repair system. A diagram of delamination between original/repair is illustrated in Standard Practice F1131.

6.1.15.2.6 *Within Original System* - Mark an "X" on the blank line beside Within Original System if delamination has occurred between any layers of the original coating system. A diagram of delamination within original system is illustrated in Standard Practice F1131.

6.1.15.2.7 *Top Primer Coat* - Mark an "X" on the blank line beside Top Primer Coat if delamination has occurred between the innermost coat of the original coating system and the primer coat. A diagram of delamination to primer coat is illustrated in Standard Practice F1131.

6.1.15.2.8 *To Steel Substrate* - Mark an "X" on the blank line beside To Steel Substrate if all coatings have separated from the surface of the hull leaving the bare steel exposed. A diagram of delamination to steel substrate is illustrated in Standard Practice F1131.

6.1.15.2.9 *Organic Odor From Delamination Area* - The inspector should determine if there is an organic odor emanating from the delaminated area. If there is an odor from an organic solvent (such as MEK or hi-flash naphtha), circle the "YES". If there is no organic odor, circle the "NO".

6.1.15,2.10 *Sample Taken* - If samples are taken, circle the "YES", if not, circle the "NO". Samples may be taken by removing some of the delaminated paint chips and placing them into a small container. The container should be labelled with the area number, ship name and hull number, date, and inspector's name.

6.1.15.3 *Checking* - Checking is the phenomenon manifested in coatings by slight breaks in the coating that do not penetrate through the last applied coating.

6.1.15.3.1 *Degree* - Determine the degree of checking by comparing the amount of checking with the diagrams illustrated in Test Method D660. If no checking is noted in the inspection area, denote by entering "NONE" on the line beside Degree and move to paragraph 6.1.15.4.

6.1.15.3.2 *Type* - Determine the type of checking by comparing the checking of the coating system with the diagrams illustrated in Test Method D660.

6.1.15.4 Flaking

6.1.15.4.1 *Overall Extent of Failure* - Determine the overall extent of flaking by using Standard Practice F1131 and enter the number of the diagram that most closely approximates the overall extent of flaking. If there is no flaking in this inspection area, enter the number "0" (zero) and move to paragraph 6.1.16.

6.1.15.4.2 *Extent Within Affected Area* - Determine the extent within the affected area of flaking by using Standard Practice F1131 and enter the letter of the diagram that most closely approximates the extent of flaking within the affected area.

6.1.16 *Mechanical Damage*

6.1.16.1 *Overall Extent of Failure* - Determine the overall extent of mechanical damage by using Standard Practice F1131 and enter the number of the diagram that most closely approximates the overall extent of corrosion due to mechanical damage. If there is no corrosion due to mechanical damage in this inspection area, enter the number "0" (zero) and move to paragraph 6.1.17.

6.1.16.2 *Extent Within Affected Area* - Determine the extent within the affected area of corrosion due to mechanical damage by using Standard Practice F1131 and enter the letter of the diagram that most closely approximates the extent of corrosion due to mechanical damage within the affected area.

6.1.16.3 *Type of Damage* - If corrosion due to mechanical damage has occurred, use the photographic examples of Standard Practice F1131 to identify the type of mechanical damage. On the inspection form, circle the type of damage (scraping/impact or internal welds/burn marks) that has occurred.

6.1.17 *Tests*

6.1.17.1 Adhesion - Adhesion is the coating's ability to remain on the substrate.

6.1.17.1.1 *Test Method* - Record the test method used from either Test Methods D3359 or Test Method D4541.

6.1.17.1.2 *Equipment* - Record the equipment used for the adhesion test method used from either Test Methods D3359 or Test Method D4541.

6.1.17.1.3 *Measurement* - Enter the five measurements taken for every 100 square meters within the inspection area.

6.1.17.2 Dry Film Thickness - Measurements of dry film thickness are of great importance because the protection of the substrate is directly related to the thickness of the coating. Coating thicknesses can be determined by either Test Methods D1186, Test Method D1400, or Test Method D4138 depending on the substrate material and whether destructive or non-destructive tests are to be performed. If destructive measurements are performed, repair damaged areas by spot cleaning, touching up with primer, and finishing all surfaces of disturbed areas. Five measurements shall be randomly taken every 100 square meters within the inspection area.

6.1.17.3 *Hardness* - Determine the coating film hardness by performing the procedure described in Test Method D3363. Five measurements shall be randomly taken every 100 square meters within the inspection area.

6.1.18 *R*emarks - Indicate specific and overall comments which the inspector feels will assist the ship owner and operator in assessing the condition of the coating system.

6.2 Responsible Personnel - Indicate all persons (name, employer, position, telephone number) whose presence is required at the time of inspection, and a procedure to follow in the event of their absence or delay.

6.3 Timing and Frequency - Inspections shall adhere to the survey requirements of the vessel based upon the latest guidance provided by the International Association of Classification Societies or every 30 months, whichever is more frequent.

6.4 Notification - Develop a procedure which establishes a specific method for notifying all responsible parties that a ship area is ready for inspection.

6.5 Record Keeping - All elements of Figure 1 shall be filled in. Exceptions include "Maintenance Coating System" information which may not apply and the "Remarks" section if no comments are applicable. A procedure shall be in place to determine the distribution of the inspection report.

7. Keywords

7.1 assessment; coating; inter-hull; inspection; corrosion

Ship and Hull Number ______________________________
Date ______________________________
Location ______________________________
Inspector's Name ______________________________
Inspector's Signature ______________________________
Tank Number ______________________________

Original Coating System	1st Maintenance Coating System	2nd Maintenance Coating System
Surface Preparation ________	Surface Preparation ________	Surface Preparation ________
Year Applied _____	Year Applied _____	Year Applied _____
Primer __________	Primer __________	Primer __________
Midcoat __________	Midcoat __________	Midcoat __________
Midcoat __________	Midcoat __________	Midcoat __________
Topcoat __________	Topcoat __________	Topcoat __________

I. Photographs
- A. Entire Area
- B. Close-Up of All Damage

II. Inspection Area .... ______________

III. Inspection Area Percentage .... ______________

IV. Inspection Area Obscured? Yes No

V. Ratings
- A. Corrosion
  - 1. General Corrosion
    - a. Overall Extent of Failure ....___________
    - b. Extent Within Affected Area .... ___________
    - c. Scattered .... Yes
    - d. Concentrated .... Yes
    - e. Degree of Rust .... ___________
  - 2. Pitting
    - a. Size .... ___________
    - b. Shape .... ___________
    - c. Density .... ___________
    - d. Depth .... ___________

B. Coating Breakdown

1. Blistering
   - a. Overall Extent of Failure .... ___________
   - b. Extent Within Affected Area .... ___________
   - c. Size .... ___________
   - d. Density .... ___________

2. Delamination
   - a. Overall Extent of Failure .... ___________
   - b. Extent Within Affected Area .... ___________
   - c. Topcoat .... ___________
   - d. Within Repair System .... ___________
   - e. Between Original/Repair .... ___________
   - f. Within Original System .... ___________
   - g. To Primer Coat .... ___________
   - h. To Steel Substrate .... ___________
   - i. Organic Odor From Delaminated Area   Yes   No
   - j. Sample Taken ....   Yes   No

3. Checking
   - a. Degree .... ___________
   - b. Type .... ___________

4. Flaking
   - a. Overall Extent of Failure .... ___________
   - b. Extent Within Affected Area .... ___________

C. Mechanical Damage

1. Overall Extent of Failure .... ___________
2. Extent Within Affected Area .... ___________
3. Type of Damage ...... Scraping/Impact   Welds/Burns

D. Tests

1. Adhesion
   - a. Test Method .... ___________
   - b. Equipment .... ___________
   - c. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

2. Dry Film Thickness
   a. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

3. Hardness
   a. Measurement

Spot 1	Spot 2	Spot 3	Spot 4	Spot 5

VI. Remarks

VII. Responsible Personnel

Name ______________________________
Employer ___________________________
Position ____________________________
Telephone Number ____________________

Name ______________________________
Employer ___________________________
Position ____________________________
Telephone Number ____________________

Name ______________________________
Employer ___________________________
Position ____________________________
Telephone Number ____________________

Name ______________________________
Employer ___________________________
Position ____________________________
Telephone Number ____________________

FIGURE 1 Condition Assessment Inspection Form

APPENDIX E

Standard Guide for the Quality Assurance Requirements for Application of Coatings to Steel Surfaces of Inter-Hull Areas

1. Scope

1.1 This guide provides a standard guide for the quality assurance requirements for the application of coatings to steel surfaces of inter-hull areas of double hull ship designs.

1.2 It is intended for this guide to be utilized to verify the proper application of the coating system during either new build or repair/replacement of the existing coating system.

1.3 Variations or simplifications of the practice set forth herein may be appropriate for special coating work such as maintenance or qualifications of equipment suppliers shop personnel. It is not the intent of this practice to mandate a singular basis for all quality assurance.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problem associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D1186 Test Methods for Nondestructive Measurement of DFT of Nonmagnetic Coatings Applied to a Ferrous Base

D1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base

D1411 Test Methods for Water-Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes

D2200 Pictorial Surface Preparation Standards for Painting Steel Structures

D3276 Standard Guide for Painting Inspectors (Metal Substrates)

D4417 Test Methods for Field Measurements of Surface Profile of Blast Cleaned Steel

D4940 Test Method for Conductrimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives

D5162 Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates

F718 Shipbuilders and Marine Paints and Coatings Product/Procedure Data Sheet

2.2 Steel Structures Painting Council Standards:

SSPC-SP 10 Near-White Blast Cleaning

SSPC-AB 1 Mineral and Slag Abrasives

2.3 Federal Register

Volume 55 Paragraph 11798 Toxicity Characteristic Leaching Procedure

3. Definitions

3.1 *Description of Terms Specific to This Standard*

3.1.1 *Certification* - Written documentation of qualification.

3.1.2 *Quality Assurance* - A form of quality control which provides the necessary confidence that a particular task has been completed to predetermined standards of workmanship.

3.1.3 *Quality Assurance Inspector* - An individual who has worked in the coating trade and is sufficiently trained and certified to properly examine, observe, and measure conformance of the coating work to predetermined quality requirements.

3.1.4 *Painting Supervisor* - An individual who has worked in the painting trade long enough to have sufficient experience and knowledge in the practical application of coatings to properly supervise other painters.

4. Summary of Practice

4.1 This practice establishes the quality assurance requirements for the coating application in the inter-hull areas of double hull ship designs and is intended to increase the confidence for the proper application of the coating system for an expected service life of 15 to 20 years.

4.2 This standard will identify who will perform the inspection, when the inspections shall be conducted, how frequently the inspections shall be conducted, quality assurance form for recording the results of each quality assurance check point, and methodology for correction of a quality assurance attribute which fails a check point.

5. Performance

5.1 The shipbuilder shall maintain a certification program for the quality assurance (QA) inspector. The QA inspector must be proficient in determining the acceptability of surface preparation prior to commencement of coating application, determining the degree of compliance with blasting and painting procedures appropriate to the surface preparation and coating materials being used, and determining the acceptability of finished products in accordance with established standardized acceptance criteria. The coating inspector's training, as a minimum, shall be certified by the Council of Engineering and Scientific Specialty Board (CESB).

5.2 The QA inspector shall be properly outfitted to perform the inspections described herein. In addition to the equipment listed in this guide, the inspector shall have a pencil and note pad to make appropriate notes. The QA forms should be filled in with a pencil during the inspection and photocopies of the filled in forms should be signed in ink. The signed copy of the inspection form shall be maintained as part of the permanent QA record.

5.3 The QA inspector is responsible for the inspection of material receipt and storage, environmental conditions, rounding of edges, abrasive blast profile, substrate chloride concentration, stripe coat completeness, dry film thickness readings, holiday check, and damage and spot repair work completeness.

5.4 The inspection of material receipt and storage facilities shall be done periodically (i.e., prior to seawater ballast tank work in each new build ship or major repair of sea water ballast tanks in an in-service ship) to ensure paints are being stored and receipt inspected in accordance with ASTM F718 and that the abrasive blast media conforms to quantitative requirements. All requirements of the coating manufacturer's Material Safety Data Sheets

(MSDS) shall be adhered to by the shipbuilder.

5.4.1 The abrasive blast media shall conform to limits for crystalline silica, chloride content, conductivity, toxicity, and hardness. These limits shall be verified at least for every batch or barge load of abrasive blast media or whenever the blast media is provided by a different supplier.

5.4.1.1 The manufacturer of the abrasive blast media shall certify that the maximum crystalline silica content of the abrasive is less that 1.0 percent by weight. Crystalline silica shall not be intentionally added to the abrasive media.

5.4.1.2 The chloride content of the abrasive shall be less than 0.03 percent by weight. Test for chloride content shall be in accordance with ASTM D1411.

5.4.1.3 The conductivity of the abrasive shall be less than 290 microsiemens per square centimeter. Test for conductivity shall be in accordance with ASTM D4940.

5.4.1.4 The manufacturer shall certify that the toxicity characteristic content of the abrasive media shall not exceed the values listed in Federal Register (FR), Volume 55, paragraph 11798, March 19, 1990 (55 FR 11798), Toxicity Characteristic Leaching Procedure (TCLP).

5.4.1.5 The abrasive material shall have a minimum hardness of 6 on the Moh's scale.

5.5 The QA inspector is required to examine all environmental data maintained by the painting supervisor. The environmental conditions shall be monitored at least every 4 hours for temperature, dew point, and relative humidity and recorded on a form similar to Figure 1. The initial reading shall be taken directly prior to the start of abrasive blasting. The environmental conditions within the inter-hull space to be preserved shall conform to the requirements of the coating manufacturer's MSDS sheets. Questions relating to the coating manufacturer's MSDS sheets shall be brought to the attention of the coating manufacturer's representative and resolved between representatives of the coating manufacturer, shipbuilder, and ship owner prior to coating application.

5.5.1 *Thermometers*-The painting supervisor may need several types of thermometers and should have at least an accurate pocket thermometer with a range from about 0 to 150^{0}F (-18 to 65^{0}C) for measuring the ambient air temperature. The same thermometer or a floating dairy thermometer may be used to determine the temperature of liquid coating, solvent, etc. The pocket thermometer may also be used for determining the temperature of metal surfaces by placing it against the metal while shielding the outer (away from the metal) side of the bulb by means of putty or similar material, so that the reading is not affected by the ambient temperature. Flat surface-temperature thermometers are also available for this purpose.

5.5.2 *Dew Point*-A psychrometer containing a wet and dry-bulb thermometer for determining relative humidity and dew point is recommended. Hand-held sling or electrical types are available as well as direct reading digital types.

5.6 It has been observed that when paint is applied to a sharp edge, the paint will draw away from the sharp edge leaving the edge with relatively poor paint coverage compared to the remaining flat surfaces. There is strong evidence that suggests radiusing or rounding sharp edges will promote improved coating performance.

5.6.1 The rounding of edges by the shipbuilder shall be verified by the QA inspector. Edge radiuses shall be a minimum of 3 mm and shall be measured at least every 100 linear feet (30 linear meters) with a prefabricated template. No more than 10 percent of the total number of measurements shall be below 3 mm and no measurement shall be less than 2.7 mm. Satisfactory completion of rounding shall be denoted by the QA inspector on Figure 2.

5.7 Abrasive blast cleaning is used to remove foreign materials from the substrate and to provide a roughened surface by striking the substrate with a stream of small, hard abrasive particles such as dry mineral, grit, slag, and shot.

5.7.1 Mineral and slag abrasives shall meet the requirements of SSPC-AB 1.

5.7.2 The QA inspector shall verify each inter-hull space has been properly abrasive blasted to near white metal in accordance with SSPC-SP 10 or equivalent by signature on Figure 3. Surface preparation is one of the most important factors affecting the performance of the coating system. Wherever possible, the vacuum blast method is recommended. There should be no dust on the surface during this part of the inspection.

5.7.1 Pictorial Standard ASTM D2200 (SSPC-Vis 1) should be provided to the inspector. The standard is used by the inspector to determine whether the degree of surface preparation specified (SSPC-SP 10) has been attained throughout the affected space.

5.7.2 The average surface profile shall be 2.0 to 4.0 mils based upon a minimum of five measurements per 100 square meters or as required by the contract. Profile measurements shall be performed per ASTM D4417 Method C, Replica Tape Method. Individual QA data shall be recorded on Figure 3 or equivalent, signed by the QA inspector, and retained as part of the permanent QA record.

5.8 Surface contamination with chlorides has been shown to lead to rapid blistering of an organic coating in immersion conditions. The basic mechanism is likely due to osmotic pressure developed under the coating when it acts as a semi-permeable membrane.

5.8.1 The QA inspector shall perform surface chloride contamination checks on freshly blasted surfaces, using the cotton ball swab method of collection followed by titration or the Bresle blister patch method. Measurements shall be made randomly over blasted surface at different locations in the inter-hull space. One measurement per 100 square meters shall be made. If any direct measurement exceeds 3 $\mu g/cm^2$ of chloride, a high pressure water wash of the surface is required. Satisfactory substrate chloride concentrations of 3 $\mu g/cm^2$ or lower shall be noted by the QA inspector by signature on Figure 4.

5.9 Dry film thickness (DFT) measurements are of great importance because the protection of the substrate is directly related to the thickness of the coating. There are two ways of making the measurements: nondestructively or destructively. The latter involves penetrating or cutting through the film to the substrate with a needle or blade and measuring the distance between the top and bottom of the film. This method is not recommended for inter-hull spaces. For inter-hull spaces, nondestructive film thickness measurements using Test Methods D1186 or Test Method D1400 are recommended.

5.9.1 Coating thickness measurements shall be performed at a minimum of five random areas for every 100 square meters of painted surface area for every coat of paint. DFT measurements shall be recorded on Figure 5 and shall conform to the DFT requirements of the coating manufacturer's product information sheets. Areas not having sufficient build during the final DFT readings shall be recoated until sufficient final DFT is achieved. There shall be no uncoated areas during all paint coats.

5.10 As previously mentioned, there is a tendency for the coating to pull away from the edge. This results in a much thinner coating and one that offers a much reduced barrier coating for the substrate. Since edge failure is the leading cause of tank coating failure, additional steps are required to resolve this problem. Stripe coating, in combination with radiusing, enhances the performance of the coating system on susceptible areas such as edges.

5.10.1 The QA inspector shall perform a visual inspection for satisfactory application of the stripe coats. The stripe coats shall be of contrasting colors to one another and to the initial prime coat. The stripe coat shall encompass all edges, as well as a 2.5 cm border outside each edge. The stripe coat thickness should be nominally 4 to 5 mils DFT and shall be neat in appearance, with minimal streaks and drops of paint. DFT measurements shall be noted on Figure 5. Paint sags and drips shall be brushed out immediately to prevent the curing of excessive thicknesses.

5.11 The QA inspector shall conduct a holiday check of the coating system applied per ASTM D5162 Practice for Discontinuity Testing of Nonconductive Protective Coating on Metallic Substrates. Results of the holiday checks shall be noted on Figure 5. All holidays shall be marked and appropriately repaired as per the coating manufacturer's product information sheet or coating manufacturer's representative directions.

5.11.1 The QA inspector shall use an inspection mirror for viewing under beams, under pipes, behind stiffeners, and other hard to spray areas for areas with no or insufficient coating coverage.

5.12 All areas damaged by weld repair, removal of staging, or other means shall be prepared to a bare metal SSPC-SP 11 finish using a profile producing mechanical tool or combination of tools. All damaged areas shall be noted on Figure 5. The intact coating around the repaired surface shall be "feathered" to create a smooth transition between coated and cleaned areas. Hand brush two coats of the coating system to the bare metal areas. Final system DFT readings in these areas shall conform to the requirements of the coating manufacturer's product information sheets.

6. Records

6.1 A personnel qualification records file shall be established for each QA inspector and be maintained by the shipbuilder.

6.2 Collection, storage, and control of records required by this guide shall be in accordance with the requirements of the shipbuilder and ship owner.

7. Keywords

7.1 quality assurance inspector; coatings inspection; corrosion; environmental conditions; substrate chloride; dry film thickness; holiday check; stripe coats

DATE	TIME	MEASUREMENT LOCATION	SUBSTRATE TEMP (^{0}C)	WET BULB	DRY BULB	%RH	DEW POINT

FIGURE 1 Environmental Readings

DATE:

LOCATION (FRAME,INBOARD, OUTBOARD, LEVEL, ETC.)	SATISFACTORY EDGE ROUNDING	INSPECTOR'S SIGNATURE

FIGURE 2 Rounding of Edges

DATE: ____________________
ABRASIVE MATERIAL: ____________________

LOCATION (FRAME, INBOARD, OUTBOARD, LEVEL, ETC.)	CLEANLINESS TO SSPC-SP 10	BLAST PROFILE	INSPECTOR'S SIGNATURE

FIGURE 3 Abrasive Blasting

DATE:

LOCATION (FRAME, INBOARD, OUTBOARD, LEVEL, ETC.)	CHLORIDE READING	INSPECTOR'S SIGNATURE

FIGURE 4 Chloride Readings

1. **DRY FILM THICKNESS (DFT):** MEASUREMENTS

COAT NO. & LOCATION	SPOT 1	SPOT 2	SPOT 3	SPOT 4	SPOT 5	AVERAGE

2. **HOLIDAY CHECK:**

DATE:

LOCATION (FRAME, INBOARD, OUTBOARD, LEVEL, ETC.)	SATISFACTORY (YES OR NO*)	INSPECTOR'S SIGNATURE

*: CORRECTIVE ACTION REQUIRED IF HOLIDAY CHECK IS UNSATISFACTORY

3. **DAMAGED AREAS:**

DATE:

LOCATION (FRAME, INBOARD, OUTBOARD, LEVEL, ETC.)	SATISFACTORY (YES OR NO*)	INSPECTOR'S SIGNATURE

*: CORRECTIVE ACTION REQUIRED IF HOLIDAY CHECK IS UNSATISFACTORY

FIGURE 5 DFT, Holiday, and Damaged Area Checks

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APPENDIX F

Standard Guide for the Training of Journeyman Painters, Painting Supervisors, and Paint Inspectors for Double Hull Ships

1. Scope

1.1 This guide provides a training plan to assist in the qualification of journeyman painters, painting supervisors, and paint inspectors to apply, supervise, and inspect the application of specified coatings to inter-hull designed ships.

1.2 Variations or simplifications of this guide may be appropriate for special coating work outside the emphasis of the inter-hull spaces of ships. It is not the intent of this guide to mandate a singular basis for all training plans and subsequent qualification.

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problem associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base

D4138 Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Methods

D4228 Practice for Qualification of Journeyman Painters for Application of Coatings to Steel Surfaces of Safety-Related Areas in Nuclear Facilities

D4286 Practice for Determining Coating Contractor Qualifications for Nuclear Powered Electric Generation Facilities

D4414 Practice for Measurement of WFT by Notch Gages

D4537 Guide for Establishing Procedures to Qualify and Certify Inspection Personnel for Coating Work in Nuclear Facilities

D5162 Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates

3. Definitions

3.1 *Journeyman Painter* - An individual who has sufficient experience in the painting trade to master the use of all applicable tools and the materials being applied.

3.2 *Painting Supervisor* - An individual who has worked in the painting trade long enough to have sufficient experience and knowledge in the practical application of coatings to properly supervise other painters.

3.3 *Paint Inspector* - The designated representative of the owner or of the coatings manufacturer, or both, who has sufficient experience and knowledge in the practical application and evaluation of coatings applied to steel surfaces.

3.4 *Governing Documents* - Technical specifications, job site procedures, and reference materials.

4. Significance and Use

4.1 The requirements of this guide apply to personnel who perform the tasks of (1) painting, (2) painting supervisor, (3) paint inspector.

4.2 It is the responsibility of each organization participating in the project to ensure that only those personnel within their respective organizations who meet the requirements of this guide are permitted to perform the duties and activities covered by this guide.

4.3 The organization(s) responsible for establishing the applicable requirements for activities covered by this guide shall be identified, and the scope of their responsibility shall be documented. Delegation of this responsibility to other qualified organizations is permitted and shall be documented.

4.4 It is the responsibility of the organization performing these activities to specify the detailed methods and procedures for meeting the requirements of this guide, unless they are otherwise specified in the contract document.

5. Requirements for Journeyman Painter

5.1 This guide requires the journeyman painter to know the required safety rules and regulations which govern proper gas freeing of spaces, emergency egress from the painting operation, and other specific safety requirements of the job site. The painter shall be properly outfitted with all required personnel protective equipment.

5.2 The journeyman painter shall be familiar with the various standards of surface preparation.

5.3 The journeyman painter shall be familiar with the coating materials mixing requirements and shall demonstrate proper mixing procedures.

5.4 The journeyman painter shall be familiar with paint application techniques associated with brush, roller, conventional spray, airless spray, and plural component equipments.

5.5 The journeyman painter shall demonstrate his/her ability to take wet film thickness readings using Test Method D4414 during the coating application demonstration.

5.6 The journeyman painter shall demonstrate his/her ability to apply the specified coating in a uniform Dry Film Thickness (DFT) in accordance with the governing documents, as evaluated by the paint inspector. All paint application techniques expected to be utilized in inter-hull spaces shall be demonstrated.

6. Requirements of the Painting Supervisor

6.1 The painting supervisor shall be trained to understand the requirements for gas freeing spaces to be painted and his/her responsibilities for ensuring these spaces are properly gas freed. For example, the painting supervisor shall ensure adequate lighting and ventilation is provided in the tank and that a proper gas free certificate has been issued and posted in a conspicuous location by the gas free engineer.

6.2 The painting supervisor shall be trained to understand his/her responsibilities to ensure the journeyman painters assigned to him/her have been provided with and are properly wearing all personnel protective equipment.

6.3 The painting supervisor shall be trained to and be familiar with the proper and safe erection of staging in the tank to properly prepare and paint all interior surfaces of the tank.

6.4 The painting supervisor shall be trained to understand the importance of maintaining the proper environmental conditions in inter-hull spaces to support the preservation of these spaces and shall ensure the requirements of these conditions are in accordance with the governing documents.

6.5 The painting supervisor shall be trained to identify the equipment necessary to take temperature readings of the space, the steel surface, dew point, and relative humidity, and to ensure these readings are taken in accordance with the governing documents. The painting supervisor shall be knowledgeable in the corrective procedures to take in the event environmental conditions within the inter-hull area are not within the prescribed requirements of the governing documents.

6.6 The painting supervisor shall be trained and be familiar with various surface cleaning methods such as abrasive blasting, vacuum blast, hydroblast, hand tool cleaning, and power tool cleaning for inter-hull spaces as well as the disadvantages and advantages of each cleaning method.

6.7 The painting supervisor shall be familiar with the surface preparation requirements of the inter-hull spaces and ensure the painters under his/her supervision have complied with the requirements of the governing documents. To do so, the painting supervisor shall be familiar with and have access to pictorial examples of the surface cleanliness standards required by the governing documents.

6.8 The painting supervisor shall ensure the coating materials are properly mixed in accordance with the governing documents.

6.9 The painting supervisor shall be trained to properly use all the necessary equipment for the proper application of the specified coating. Their knowledge must be sufficient to provide the necessary guidance and recommendations to the painters under their supervision to ensure the requirements of the governing documents are met.

6.10 The painting supervisor shall be trained to ensure WFT and DFT readings of the painted surfaces are taken to verify that the proper paint thicknesses have been applied by the painters in accordance with the governing documents. All areas which do not comply with the requirements of the governing documents shall be repaired to meet these requirements.

6.11 The painting supervisor shall be knowledgeable on the coating repair requirements set forth in the governing documents and to provide the necessary guidance to his/her painters to comply properly with these requirements in repairing the deficient areas.

7. Requirements of the Paint Inspector

7.1 The paint inspector shall be capable of implementing and recording all inspections required by the governing documents and governing bodies (ship owner, classification society, authorities, shipyard, sub-contractors, labor organizations, etc.).

7.2 The paint inspector shall possess knowledge and experience in the following area: different types of vessel and structural elements; function and method of operation of inter-hull spaces; preparation and use of specifications; inspection planning; safety and safety procedures; rigging of scaffolding and accessibility; steel work; surface preparation methods and equipment; properties of different coating systems; selection and application of coatings;

climate control and ventilation; cathodic protection; quality control and testing; use of and calibration of measurement equipment; characterization and assessment of different types of corrosion; identification and assessment of different types of coating damage; use of different types of inspection equipment; familiar with all aspects of the inspection requirements of the governing documents.

8. Examination

8.1. The journeyman painter shall apply the specified coating in conformance to the governing documents to a test panel similar in detail to the inter-hull space. An example of a test setup is provided in Standard Practice D4228.

8.2 The painting supervisor shall be given an examination covering the general, specific, and practical aspects of coatings application to inter-hull spaces. The examination should be both written and practical.

8.3 The paint inspector shall be given an examination covering the general, specific, and practical aspects of coatings inspection. The examination can be either written, in the form of a personal interview, or a combination of both.

9. Evaluation

9.1 Evaluation of the journeyman painter shall be made by the painting supervisor and the paint inspector. Both individuals shall be thoroughly familiar with the specified coating material(s) and acceptance criteria and shall be aware of any difficulties in applying the coating on surfaces similar to that found in inter-hull spaces.

9.1.1 The painting supervisor and the paint inspector shall take dry film thickness readings on all areas of the sample test area by either Test Methods D1186 or Test Method D4138. These readings shall be used to verify the specified dry film thickness requirements have been met and the uniformity of the coating application.

9.1.2 The painting supervisor and the paint inspector shall inspect the finished surface to verify that it conforms to the requirements of the governing documents and Practice D5162.

9.2 Evaluation of the painting supervisor shall be made by a paint inspector and a production-related qualifying agent. Both individuals shall be thoroughly familiar with the specified coating material(s), all associated safety requirements, acceptance criteria for the coating material(s), and shall be aware of any difficulties in applying the coating on any surface.

9.2.1 The paint inspector and qualifying agent shall verify the painting supervisor is proficient in the requirements listed in section 6.

9.3 Evaluation of the paint inspector shall be made by two qualifying agents. Only one qualifying agent can be production-related.

9.3.1 The qualifying agents shall be thoroughly familiar with all aspects of the specified coating material(s), the acceptance criteria for the coating material(s), the inspection requirements of the coating material(s), and all difficulties in applying the coating to the test panel.

10. Report

10.1 The report of the journeyman painter's performance shall be similar to Figure 1.

10.1.1 *Date* - Date(s) of the test.

10.1.2 *Journeyman* - Printed name of the journeyman painter.

10.1.3 *Painting Supervisor* - Printed name of the painting supervisor.

10.1.4 *Paint Inspector* - Printed name of the paint inspector.

10.1.5 *Test Panel Location* - The numbered location on the test panel where Dry Film Thickness (DFT) measurements are taken.

10.1.6 *DFT Reading* - The DFT measurements taken at each test panel location.

10.1.7 *Description of Finish Surface* - Written description by the painting supervisor and paint inspector on the qualitative appearance of the coating system on the test panel.

10.1.8 *Material* - Record the type of coating system used in the test application.

10.1.9 *DFT Range* - Record the range of acceptable DFT measurements for the coating system used in the test application.

10.1.10 *Holiday Detection* - Record the type of holiday detection equipment used on the test panel.

10.1.11 *Signature of Journeyman Painter* - Signature of journeyman painter.

10.1.12 *Signature of Painting Supervisor* - Signature of painting supervisor.

10.1.13 *Signature of Paint Inspector* - Signature of paint inspector.

10.1.14 The report shall become a permanent part of the journeyman painter's personnel record.

10.1.15 A copy of the report shall be given to the qualifying journeyman painter.

10.2 The report of the painting supervisor's performance shall be similar to Figure 2.

10.2.1 *Date* - Date(s) of the examination.

10.2.2 *Painting Supervisor* - Printed name of the painting supervisor.

10.2.3 *Paint Inspector* - Printed name of the paint inspector.

10.2.4 *Qualifying Agent* - Printed name of the qualifying agent.

10.2.5 *Examination Scores*

10.2.5.1 *General Portion* - Record the score of the painting supervisor's performance in the general portion of the examination.

10.2.5.2 *Specific Portion* - Record the score of the painting supervisor's performance in the specific portion of the examination.

10.2.5.3 *Practical Portion* - Record the score of the painting supervisor's performance in the practical portion of the examination.

10.2.6 *Comments* - Written remarks by the paint inspector and/or qualifying agent concerning the performance of the painting supervisor in the examination.

10.2.7 *Recommended By*

10.2.7.1 *Signature of Painting Supervisor* - Signature of the painting supervisor.

10.2.7.1.1 *Title* - Title of the painting supervisor.

10.2.7.2 *Signature of Paint Inspector* - Signature of the paint inspector.

10.2.7.2.1 *Title* - Title of the paint inspector.

10.2.7.3 *Signature of the Qualifying Agent* - Signature of the qualifying agent.

10.2.7.3.1 *Title* - Title of the qualifying agent.

10.2.8 The report shall become a permanent part of the painting supervisor's personnel record.

10.2.9 A copy of the report shall be given to the qualifying painting supervisor.

10.3 The report of the paint inspector's performance shall be similar to Figure 3.

10.3.1 *Date* - Date(s) of the examination.

10.3.2 *Paint Inspector* - Printed name of the paint inspector.

10.3.3 *Qualifying Agent* - Printed name of one of the qualifying agent.

10.3.4 *Qualifying Agent* - Printed name of the other qualifying agent.

10.3.5 *Examination Scores*

10.3.5.1 *General Portion* - Record the score of the painting supervisor's performance in the general portion of the examination.

10.3.5.2 *Specific Portion* - Record the score of the painting supervisor's performance in the specific portion of the examination.

10.3.5.3 *Practical Portion* - Record the score of the painting supervisor's performance in the practical portion of the examination.

10.3.6 *Comments* - Written remarks by the paint inspector and/or qualifying agent concerning the performance of the painting supervisor in the examination.

10.3.7 *Recommended By*

10.3.7.1 *Signature of Qualifying Agent* - Signature of the qualifying agent.

10.3.7.1.1 *Title* - Title of the qualifying agent.

10.3.7.2 *Signature of Qualifying Agent* - Signature of the other qualifying agent.

10.3.7.2.1 *Title* - Title of the other qualifying agent.

10.3.8 The report shall become a permanent part of the painting supervisor's personnel record.

10.3.9 A copy of the report shall be given to the qualifying paint inspector.

11. Certification

11.1 All qualifications are certified for a period not to exceed three years. All personnel are required to be recertified whenever a new coating system is stipulated to be used in the governing documents.

12. Records

12.1 As noted in section 10, personnel qualification records shall be established and maintained by the employer. The collection, storage, and control of records required by this guide shall be in accordance with the requirements of the responsible organization and appropriate governing documents.

13. Keywords

13.1 journeyman painter; painting supervisor; paint inspector; training; coatings inspection

Test Application of Coating to Standard Panel Test
by Journeyman Painter for Qualification

Date: ____________________________
Journeyman: ____________________________
Painting Supervisor: ____________________________
Paint Inspector: ____________________________

Test Panel Location	DFT Reading
#1	__________________
#2	__________________
#3	__________________
#4	__________________
#5	__________________
#6	__________________
#7	__________________
#8	__________________
#9	__________________
#10	__________________

Description of Finished Surface:

____
____
____
____

Material: ____
DFT Range: ____________________
Holiday Detection: ____________________

Signature of Journeyman Painter: ________________________________

Signature of Painting Supervisor: ________________________________

Signature of Paint Inspector: ________________________________

FIGURE 1 Record Form for Test Application for Journeyman Painter

Record of Examination of the Painting Supervisor

Date: ______________________________
Painting Supervisor: ______________________________
Paint Inspector: ______________________________
Qualifying Agent: ______________________________

Examination Scores:

General Portion ____________________
Specific Portion ____________________
Practical Portion ____________________

Comments:

____
____
____
____

Recommended by:

Signature of Painting Supervisor: ____________________________
Title: ____________________________

Signature of Paint Inspector: ____________________________
Title: ____________________________

Signature of Qualifying Agent: ____________________________
Title: ____________________________

FIGURE 2 Sample Record of Examination for the Painting Supervisor

Record of Examination of the Paint Inspector

Date: ______________________
Paint Inspector: ______________________
Qualifying Agent: ______________________
Qualifying Agent: ______________________

Examination Scores:

General Portion ________________
Specific Portion ________________
Practical Portion ________________

Comments:

____
____
____
____

Recommended by:

Signature of Qualifying Agent: ______________________
Title: ______________________

Signature of Qualifying Agent: ______________________
Title: ______________________

FIGURE 3 Sample Record of Examination for the Paint Inspector

Project Technical Committee Members

The following persons were members of the committee that represented the Ship Structure Committee to the Contractor as resident subject matter experts. As such they performed technical review of the initial proposals to select the contractor, advised the contractor in cognizant matters pertaining to the contract of which the agencies were aware, and performed technical review of the work in progress and edited the final report.

Rickard Anderson –Chairman	Military Sealift Command
James Baker	Military Sealift Command
John Burkhart	Military Sealift Command
Jadeep Sirkar	U.S. Coast Guard
Alan Bentz	U.S. Coast Guard
Chao Lin	Maritime Administration
Harvey Hack	Naval Surface Warfare Center
John S. John	American Bureau of Shipping
Ken KarisAllen	Defence Research Establishment Atlantic
Marty Hecker	U.S. Coast Guard
Prof. John McIntyre	Advanced Polymer Services
David Witmer	BP Oil Marine
Mr. William Siekierka	Naval Sea Systems Command, Contracting Officer's Technical Representative
Dr. Robert Sielski	National Academy of Science, Marine Board Liaison
CDR Steve Sharpe	U.S. Coast Guard, Executive Director Ship Structure Committee