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Alternative Control Techniques Document: Surface Coating Operations at Shipbuilding and Ship Repair Facilities

ACT

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EPA 453/R-94-032

Alternative Control Techniques Document: Surface Coating Operations at Shipbuilding and Ship Repair Facilities

Emission Standards Division

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

April 1994

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1.0 SUMMARY

1.1 INTRODUCTION

This report provides alternative control techniques (ACT) for State and local agencies to consider for incorporating in rules to limit emission of volatile organic compounds (VOC's) and particulate matter including PM_{10} (that which measures 10 microns or less) that otherwise would result from surface coating operations at shipbuilding and ship repair facilities. This document contains information on emissions, controls, control options, and costs that State and local air pollution authorities can use in developing rules. The document presents options only, and makes no recommendations.

As a parallel project, the U. S. Environmental Protection Agency (EPA) is developing a national standard to regulate hazardous air pollutant (HAP) emissions from this source category. Those rules are still well over a year away.

1.2 ALTERNATIVE CONTROL TECHNIQUES

Most of the VOC's contained in marine coatings are emitted to the atmosphere as the paint is applied and cures. Most of the painting work is performed outdoors. The massive scale of a ship makes it difficult to capture the emissions from outdoor painting, unlike for example, painting the inside of a tank where the tank provides a natural enclosure, hence abatement equipment has not previously been used.

The emission points defined for this source category are indoor and outdoor painting operations. A number of alternative control techniques for surface coating operations in the shipbuilding and ship repair industry were compared. Several control options were evaluated. These include availability of coatings with inherently lower emissions of VOC's (and associated HAP's) and use of add-on control devices. Coatings that comply with the California 1992 and 1994 (Rule 1106, Marine Coating Operations) limits for the paint categories identified in Table 1-1 are the primary basis for the alternative control techniques presented here. Many of the resulting compliant coatings have survived the Navy's lengthy performance testing program and appear on the Navy "Qualified Products List", hence are acceptable for use on Navy ships. Coatings with even lower emissions are available for certain coating categories listed in Table 1-1, they reportedly have not been fully tested and approved by the NAVY. Such materials were not considered in this report although the Navy has some of them undergoing standardized multi-year exposure testing VOC limit.

Four lower VOC options of this alternative control technology were investigated for "major-use" coating categories in the project "data base.[1]" Three of the options (Nos.1,2 & 4) set maximum or not-to-be-exceeded limits. The fourth option (No. 3) places no limit on individual coatings but rather allows calculation of a weighted average.

The three paint categories that make up about 90% of the paint volume (as reported in the data base) for this industry are: "general use" (epoxies, 60 % and alkyds, 10 %), antifoulants (10 %), and inorganic zincs (10 %). The nationwide emission reduction achievable for each of the four coating categories was calculated based on imposing limitations in all

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[1] The "data base" is the paint information collected as a result of an information request mailed to this industry.

nonattainment areas, equal to the corresponding California limits. It was assumed that relative paint usage among the categories would not change.

Cost and environmental impacts of potential rules were developed using "model" shipyards to represent the range of facilities found in this industry. Eight models were developed to represent the various types of shipyards that could be covered by the ACT.

The relative size of the yard and whether it does new ship construction or repair were the bases for categorization resulting in: (1) large/construction; (2) large/repair; (3) medium/ construction; (4) medium/repair; (5) small/construction; (6) small/repair; (7) extra small/construction; and (8) extra small/repair. Size is characterized by annual volume of paint and solvent usage which affects annual VOC emission levels (Mg/yr).

Cleaning solvents constitute an important source of VOC emissions They are used to remove contaminants such as dirt, soil, oil, and grease to prepare the substrate for painting. Equipment, vessels, floors, walls, and other work areas are also cleaned using solvents. To aid States develop rules to control emissions from the use of VOC-containing cleaning solvents in the marine industry, earlier this year EPA published a report titled "Alternative Control Techniques Document for Industrial Cleaning Solvents" (EPA-453/R-94-015).

This study of shipyards revealed great confusion regarding the use of "thinning", "reducing" or "dilution" solvents. Added to the paint just prior to spraying, thinning solvents reduce the viscosity of the paint as supplied by its manufacturer.

Enormous amounts of thinning solvents are used, yet many paint manufacturers indicated that such use is largely unnecessary; the paints are delivered in a ready to spray condition for most climatological conditions.

Viscosity can also be controlled via use of "paint heaters", commercial portable electrical heaters mounted in the paint delivery lines. These are widely used throughout paint manufacturing industries.

The viscosity of a paint increases with decreasing temperature. Northern-located shipyards, such as the Bath Yard in Maine, argue that paint heaters are unsuitable for their unique yard orientation and that addition of dilution solvent is critical to their ability to paint during extreme weather conditions.

The use of abrasive blasting media to remove rust and deteriorated coatings before painting a marine surface results in huge emissions of particulate including PM_{10}. This document provides an overview of several blasting systems and blasting mediums commonly used. It also provides information on technologies under development that would significantly reduce these emissions: a vacuum blast cleaning system marketed in Europe and a self-supporting portable enclosure being developed in the U.S. Existing regulations for VOCs and PM_{10} and demonstrated control technologies that are transferable to ship yards are discussed in this document.

The alternatives presented herein provide no distinction between record keeping and reporting in shipbuilding and construction yards. Although yards may already be required to maintain records to satisfy permit conditions and requirements of the Superfund Amendments and Reauthorization ACT of 1986 (SARA 313), the VOC limits will require additional records be maintained.

As with rules for other industries, the alternative which provides greatest flexibility to the shipyard has a price - more detailed records and computations.

1.3 ENVIRONMENTAL IMPACT

Those normally result from a rule that mandates that add-on control equipment be installed to control emissions that the process generates. The bulk of the alternatives herein are based on a pollution prevention approach; use of coatings with inherently lower air pollution potential.

1.4 Inorganic Zinc Coatings

Categories of coatings in Table 1-1 differ from the California rule in two respects. These changes were made late in the study based on an increased understanding of two different coating operations. Two distinctly different inorganic coatings have traditionally contained zinc. Zinc rich coatings offer excellent corrosion resistance because the metal acts as a sacrificial anode in the electrochemical corrosion phenomena. One type has long been used in a thick (3 to 5 or more mils) application as a prime coat which is overcoated with top coats to protect the zinc. A second type, so called "weld-through" or "preconstruction primer" is applied as a temporary coating to protect steel plate while in inventory (usually outdoors) at the shipyard. These coatings are used in a thin film (nominal 1 mil) to minimize both cost and available zinc in the weld zone that contaminates the weld during the welding process. If a thicker film were used, it is reported that the incremental zinc would reduce the integrity of the resulting weld.

Lower VOC coatings of similar chemistry are generally more viscous. As a result, thin films are difficult to apply with conventional high build inorganic zinc coatings. Failure to include a category that allows higher VOC weld-through primers would require that the high build coating be blasted or ground off of the steel plate before welding operations could take place. The time, labor cost and pollution that would result argue for providing a category for the unique properties of weld-through primers, limited to only those coatings applied prior to and in preparation for subsequent welding operations.

Because the weld-through products yield greater volatile organics per volume of paint solids, it appears that abatement of those emissions may be reasonable under some circumstances. Use of automated systems to apply such high VOC products apparently results in sufficient VOC to render the cost of control reasonable. One shipyard indicated that it is installing abatement on its automated, preconstruction primer line. This information was gathered too late in the study to permit a detailed evaluation of the either the process or its cost, so a State must evaluate each situation on a case-by-case basis. The control costs presented in this report do not apply to an automated system; they were developed for situations that would be far more costly to control.

TABLE 1-1. VOC LIMITS FOR SHIPBUILDING COATING CATEGORIES

Coating category	VOC limits[a]	
	Grams per liter (g/L)	Pounds per gallon (lb/gal)[b]
General use	340	2.83
Specialty	--	--
Air flask	340	2.83
Antenna	530	4.42
Antifoulant	400	3.33
Heat resistant	420	3.50
High gloss	420	3.50
High temperature	500	4.17
Inorganic zinc high build primer	340	2.83
Weld-through (shop) primer	650	5.42
Military exterior	340	2.83
Mist	610	5.08
Navigational aids	550	4.58
Nonskid	340	2.83
Nuclear	420	3.50
Organic zinc	360	3.00
Pre-treatment wash primer	780	6.50
Repair and maintenance of thermoplastic coating of commercial vessels	550	4.58
Rubber camouflage	340	2.83

Coating category	VOC limits[a]	
	Grams per liter (g/L)	Pounds per gallon (lb/gal)[b]
Sealant coat for thermal spray aluminum	610	5.08
Special marking	490	4.08
Specialty interior	340	2.83
Tack coat	610	5.08
Undersea weapons systems	340	2.83

[a] VOC content limits are expressed in units of mass of VOC (g, lb) per volume of coating (L, gal) less water and less "exempt" solvents as applied. Volatile compounds classified by EPA as having negligible photochemical reactivity are listed in 40 CFR 51.100(s).

[b] To convert from g/L to lb/gal, multiply by:

[(3.785 L/gal)(lb/453.6 g)] or (lb-L/120 g-gal).

2.0 INDUSTRY DESCRIPTION

2.1 GENERAL

For purposes of this study, the shipbuilding and ship repair industry consists of establishments that build and repair ships with metal hulls. This industry also includes the repainting, conversion, and alteration of ships. Subcontractors engaged in ship painting, blasting, or any other operations within the boundaries of a shipyard are considered to be part of the shipyard, and resulting emissions are considered shipyard emissions. The definition for Standard Industrial Classification (SIC) Code 3731, Shipbuilding and Repairing, generally coincides with the above definition but differs in that SIC Code 3731 includes the manufacture of both offshore oil and gas well drilling and production platforms. Limits on emissions from coatings used on such platforms are being negotiated as part of the Federal VOC rule on architectural and industrial maintenance coatings which is still under development. In order to better define which shipyard facilities will be subject to rulemaking, the following definition of a ship has been adopted:

> any metal marine or fresh-water metal hulled vessel used for military or commercial operations, including self-propelled vessels and those towed by other craft (barges). This definition includes, but is not limited to, all military vessels, commercial cargo and passenger (cruise) ships, ferries, barges, tankers, container ships, patrol and pilot boats, and dredges.[1]

Pleasure craft such as recreational boats and yachts are not included in the definition and are not typically built or serviced in large-scale shipyards. As would be expected, there is some overlap with the pleasure craft industry. Some of the smaller shipyards work on both ships and pleasure craft.

Approximately 437 facilities (shipyards) of varying capabilities are involved in the construction and repair of ships in the United States.[2] This number includes eight Naval shipyards and one Coast Guard facility. The shipyards are located along the east, west, and Gulf coasts as well as at some inland locations along the Mississippi River (and its tributaries) and the Great Lakes. Many of the small bargeyards are concentrated in Louisiana and Texas. The majority of these do not qualify as major sources with regard to volatile organic compound (VOC) and/or particulate matter 10 microns or less in diameter (PM-10) emissions (as discussed in Chapter 4). Figure 2-1 shows the geographical location of active U.S. shipyards, and Table 2-1 lists individual States, with the number of shipyards located in each.

As reported in the U.S. Industrial Outlook '92--Shipbuilding and Repair dated January 1992:[3]

> The U.S. Active Shipbuilding Base (ASB) is defined as privately-owned shipyards that are open, engaged in, or actively seeking construction contracts for naval and commercial ships over 1,000 tons. These full-service yards are the primary sector of the first-tier shipyards, which are facilities capable of constructing, drydocking, or topside-repairing vessels 400 feet in length or more. As of October 1, 1992, there were 16 ASB shipyards. The ASB shipyards continue to employ about three-quarters of the shipbuilding and ship repair industry's total work force of more than 120,000. These figures do not include nine Government-owned shipyards, which do not engage in new construction, but rather in the overhaul and repair of Navy and Coast Guard ships.
>
> Another important sector of the shipbuilding and

Figure 2-1. 437 active U.S. shipbuilding facilities (by State).

TABLE 2-1. U.S. SHIPYARD LOCATIONS[2]

State	No. of shipyards
Louisiana	74
Texas	53
Virginia	34
California	33
Florida	33
Washington	25
New York	21
Mississippi	17
Alabama	15
Pennsylvania	12
Oregon	10
Wisconsin	9
Massachusetts	8
Maine	7
New Jersey	7
Ohio	7
Indiana	6
Illinois	6
North Carolina	6
South Carolina	6
Michigan	6
Rhode Island	6
Tennessee	6
Missouri	5
Hawaii	5
Georgia	4
Maryland	4
Puerto Rico	3
Alaska	2
Arkansas	2
Connecticut	2
Minnesota	1
Oklahoma	1
New Hampshire	1
TOTAL	437

> ship repair industry is one composed of small-size and medium-size facilities, or "second-tier shipyards." These shipyards are primarily engaged in supporting inland waterway and coastal carriers. Their market is the construction and repair of smaller type vessels, such as tug boats, supply boats, ferries, fishing vessels, barges, and small military and Government-owned vessels.[3]

Shipyard employment varies from 10 employees to 26,000 employees, and subcontractors are used frequently for specific operations like abrasive blasting and painting. Bargeyards typically are relatively smaller operations with a focus on repair activities, while most commercial and military shipyards have more employees and can handle a wide variety of ships and repairs.

All types of vessels are built or repaired in shipyards in the United States. Many of the ships are foreign-owned/operated. Government owned (Navy, Army, and Coast Guard) vessels account for a significant portion of all shipyard work. Steel is the most common material used in the shipbuilding and ship repair industry, but wood, aluminum, and plastic/fiberglass are also used.

The large shipyard organizations that have floating drydocks and/or graving docks generally have extensive waterfront acreage and are capable of all types of ship repair and maintenance. Major shipyards usually combine repair, overhaul, and conversion with shipbuilding capabilities, and employment usually numbers in the thousands. It is difficult to draw a sharp line between yards that build and ships and those that repair; many facilities engage in both to various degrees. The mix of work varies widely throughout the industry as well as from year to year at a single shipyard.[3,4]

Repair yards perform a wide variety of services and can be categorized into two groups based on the ability to drydock a ship. Those facilities which have no drydock capabilities are known as topside repair yards and can perform the various repairs that do not require taking a ship out of the water. Services rendered by these yards may vary from a simple repair job to a major topside overhaul. In general, topside yards do not do a lot of painting so they have low VOC emissions and gnerally do not qualify as major sources. On the other hand, typical repair yards with the ability to drydock ships do more painting than do construction yards of comparable size since repainting is an integral part of most repair jobs and the underwater hull is a significant part of the painted area of a ship.

2.2 PROCESSES AND EQUIPMENT

The vast majority of emissions from shipyards are VOC's, and most of those come from organic solvents contained in marine paints and solvents used for thinning and cleaning. For that reason, the focus of this CTG is on painting operations within shipyards. The VOC emissions associated with the use of solvents for cleaning were addressed by publication of an alternative control techniques (ACT) document for industrial cleaning solvents (EPA-453/R-94-015).

This section discusses related details of marine paints, resins, solvents, coating systems, and application equipment. In addition to VOC's, PM-10 is also emitted, primarily as a result of abrasive blasting surface preparation activities. The final portion of this section discusses the various processes used to prepare surfaces for painting.

Information on the processes and equipment used in this industry was based, in part, on information gathered from responses to information requests sent to shipyards pursuant to Section 114 of the Clean Air Act, EPA's information-gathering authority.[5] Information was also obtained from coating manufacturer's Section 114 responses.[6]

Due to the size and limited accessibility of ships, most shipyard painting operations are performed outdoors. When painting and/or repairs are needed below the waterline of a ship, it must be removed from the water using a floating drydock, graving dock, or marine railway. In new construction operations, assembly is usually modular, and painting is done in several stages at various locations throughout the shipyard.

The typical ship construction process begins with steel plate material. The steel plate is abrasively cleaned (blasted), and then coated with a preconstruction primer for corrosion protection during the several months it may lay in storage before it is used. The steel plate is formed into shapes or rolled. This is typically done indoors at the bigger shipyards, where some facilities have automated these steps. (Smaller shipyards usually have no indoor facilities, and all metal-forming work is done at or near the waterfront.) The preformed shapes or rolls are assembled into subassemblies which are constructed into "blocks". Blocks are blasted to bare metal to remove the preconstruction primer and a paint "system" is applied. A paint "system" is a succession of compatible coatings applied on top of one another. At some point in the construction, even those components fabricated indoors are moved outdoors to work areas adjacent to the drydock. The next construction step is on-block outfitting of piping, ventilation, and other materials. For large ships such as aircraft carriers or cruise ships final assembly (and then painting) can only be done at the drydock . At some facilities, smaller ships are completed indoors and then moved to the water using a marine railway and/or cranes.

There are five general areas of ship structures that have special coating requirements:

1. Antennas and superstructures (including freeboard);
2. Exterior deck areas;
3. Interior habitability areas;
4. Tanks (fuel, water, ballast, and cargo); and
5. Underwater hull.[4]

Each of these areas is diagrammed in Figure 2-2 to aid with some of the terminology used later in this chapter.[7]

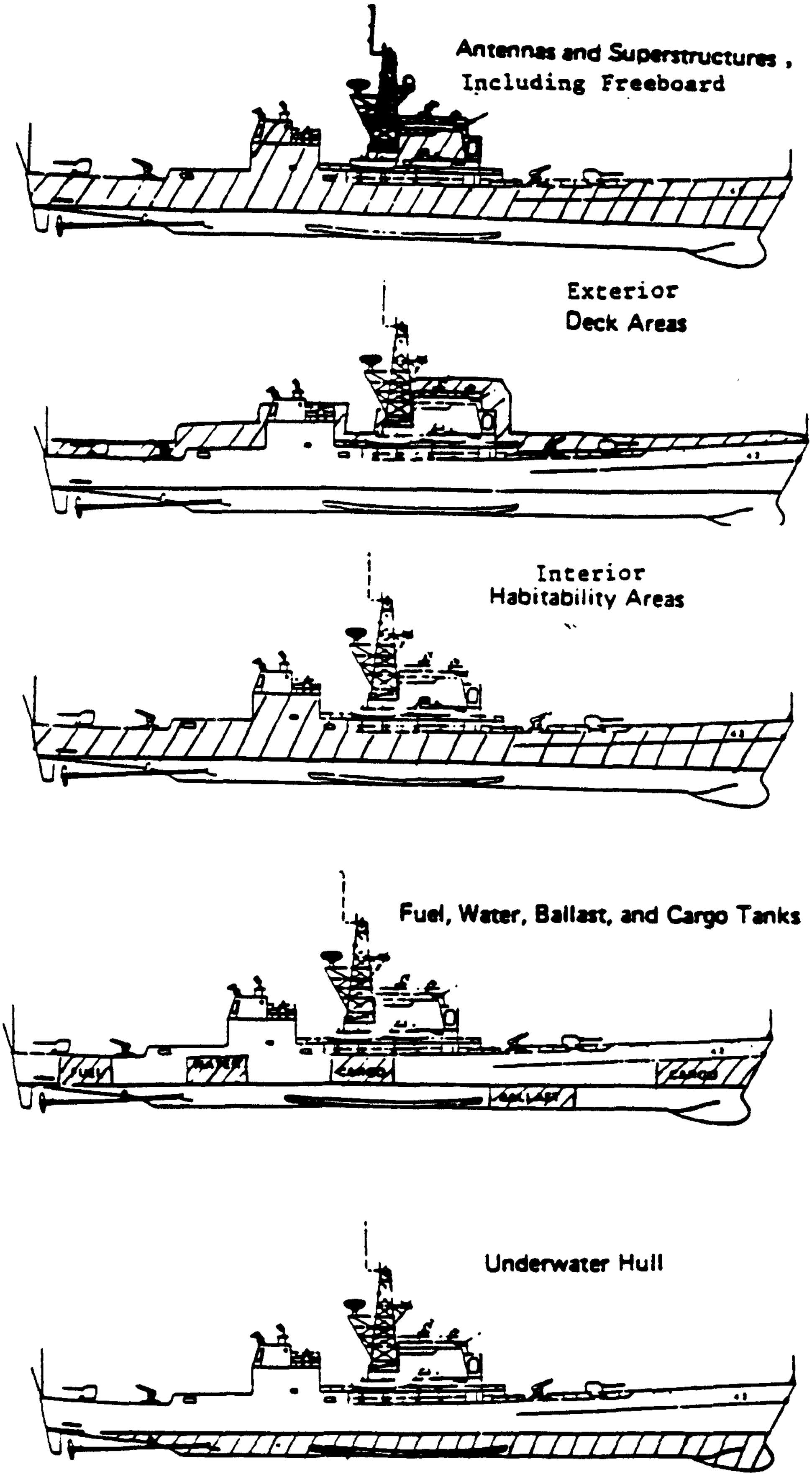

Figure 2-2. General areas of ship structures with special coating needs.[7]

2.2.1 Marine Paints

The basic components in marine paint (coatings) are the vehicle (resin binder), solvent (except in 100 percent solids coatings), pigment (except for clear coatings), and additives. Resins and solvents are discussed further later in this section. Paint is used for protective, functional or decorative (aesthetic) applications or both.[8]

Marine coatings are vital for protecting the ship from corrosive and biotic attacks from the ship's environment. Many marine paints serve specific functions such as corrosion protection, heat/fire resistance, and antifouling (used to prevent the settlement and growth of marine organisms on the ship's underwater hull). A ship's fuel consumption will increase significantly because of marine fouling, adding to the operational costs. Different paints are used for these purposes, and each may use one or more solvents (or solvent blends) in different concentrations. Specific paint selections are based on the intended use of the ship, ship activity, travel routes, desired time between paintings (service life), the aesthetic desires of the ship owner or commanding officer, and fuel costs. Ship owners and paint suppliers specify the paints and coating thicknesses to be applied at shipyards.

2.2.1.1 Marine Coating (Resin) Types. The general properties of the different chemical types of coatings and their uses in marine applications are discussed in this section. An overall summary of these coating types and applications is provided in Tables 2-2 and 2-3.[4] These marine coatings are usually applied as a "system." A typical coating system comprises (1) a primer coat that provides initial corrosion (oxidation) protection and promotes adhesion of the subsequent coating, (2) one or more intermediate coats that physically protect(s) the primer and may provide additional or special properties, and (3) a topcoat that provides long-term protection for both the substrate and the underlying coatings. The primer is usually a zinc-rich material that will provide galvanic corrosion protection if the overlying paint system is damaged but

TABLE 2-2. AREAS OF APPLICATION FOR MARINE PAINTS (RESIN TYPES)[4,7]

Where used	Alkyd	Epoxy	Inorganic zinc	Organic zinc	Polyurethane	Vinyl	Chlorinated rubber
Superstructure	X	X	X	X	X	X	X
Topside equipment	X	X	X	X	X	X	X
Decks	X	X	X		X	X	
Hull--above water line	X	X	X	X	X	X	X
--below water line		X				X	X
Internal decks	X	X			X		
Internal bulkheads	X	X			X		
Voids	X	X	X	X	X		
Engine room--surfaces	X	X					
--machinery							
Tanks		X	(a)			X	
Cargo holds--wet		X	X		X	X	
--dry		X	X		X		

(a) Commonly used for potable water tanks.

TABLE 2-3. MARINE COATING (RESIN) TYPES[4,7]

Coating type	Resin	Advantages	Disadvantages
Alkyd based	Polyester compounds	Anticorrosive and weather-resistant	Not recommended for immersion
Chlorinated rubber	Natural rubber	Water resistant Fast drying	Softened by heat
Coal tar and coal tar epoxy	Coal tar pitch	High dielectric strength Inexpensive	Carcinogenic Safety concerns
Epoxy based	Bisphenol-A-type	Anticorrosive Chemical-resistant	Sunlight-sensitive Pot life varies by formulation
Inorganic zinc	Zinc metal in an inorganic binder	Excellent primer for superstructure Galvanically active	Poor immersion service in solutions of either high or low pH
Organic zinc	Zinc metal in an organic binder	Electrochemically active	Poor immersion service in salt water
Polyurethane	Isocyanate group	Chemical-resistant High gloss	Difficult to recoat
Spray-metalized	Molten aluminum or zinc	Low weight Longer service life	Requires topcoat
Vinyl	Vinyl compounds	Chemical- and water-resistant	Softened by heat Requires wash primer

would quickly be consumed by sacrificial corrosion without a protective topcoat. A good coating system can enhance the beneficial properties of individual coatings. Each coating is typically a different color to help the applicators ensure that each layer provides complete coverage.

2.2.1.1.1 Alkyds.[9] Alkyd resins are polyester compounds that are formed by reactions between polyhydric alcohols (e.g., ethylene glycol or glycerol) and a polybasic acid (e.g., phthalic anhydride) in the presence of a drying oil (e.g., linseed or soybean oil). The specific oil used determines the curing properties of the resin and its ultimate chemical and physical properties. Alkyds are frequently modified chemically to improve their physical properties or their chemical resistance. Modified alkyds are formed by reacting other chemical compounds (such as vinyl, silicone, and urethane compounds) with the alkyd. Alkyd coatings require chemical catalysts (driers) to cure. Typical catalysts are mixtures of zirconium, cobalt, and manganese salts. Depending on the catalysts and the ambient temperature and humidity, it takes several days to several weeks before the coating is fully cured.

Alkyd coatings are frequently used as anticorrosive primers and topcoats in interior areas and as cosmetic topcoats over high-performance primers in exterior areas. Alkyd coatings are primarily used for habitability spaces, storerooms, and equipment finishes. Fire-retardant alkyd paints are some of the most common interior coatings used on Naval ships. Modified alkyds, particularly silicone alkyds, have excellent weathering properties and are good decorative and marking coatings. However, alkyds are not recommended for saltwater immersion service or for use in areas that are subject to accidental immersion. The alkali generated by the corrosion reactions rapidly attacks the coating and leads to early coating failure. Also, alkyds should not be applied over zinc-rich primers because they are attacked by the alkaline zinc corrosion products.

2.2.1.1.2 Chlorinated rubber.[9] Chlorinated rubbers are formed by reacting natural rubber with chlorine. Chlorinated rubbers by themselves are not suitable for use as coatings and must be blended with other compounds to produce good coatings. Coatings made from chlorinated rubbers that have been blended with highly chlorinated additives provide tough, chemically resistant coatings. These coatings cure by solvent evaporation. These coatings are normally partially dry within 1 hour (hr) and fully dry within 7 days. For this reason, chlorinated rubber coatings are especially useful where fast drying, particularly at low temperatures (0° to 10°C [32° to 50°F]), is required.

Chlorinated rubber coatings are tough, resistant to water, and chemically resistant. However, they are softened by heat and are not suitable for sustained use at temperatures above 66°C (150°F). Chlorinated rubber coatings are suitable for most exterior ship areas that are not continually exposed to higher temperatures.

2.2.1.1.3 Coal tar and coal tar epoxy.[9] Coal tar coatings are made from processed coal tar pitch dissolved in suitable petroleum solvents. They form a film by evaporation of the solvent, and the film can be redissolved in solvents. Coal tar films provide very good corrosion protection. However, the dry film is damaged by direct exposure to sunlight, which causes rapid, severe cracking. Coal tars are normally blended with other resins to improve their light stability and to increase their chemical resistance. Common blending resins include vinyl and epoxy materials. Coal tar coatings are widely used in highly corrosive environments such as ship bottoms, where impermeability is important. They are also applied as anticorrosive coatings in ballast tanks and lockers used to store anchor chains.

Coal tar epoxy paints are packaged with the epoxy portion in one container and the curing agent (either amine or polyamide type) in a second container. The coatings must be thoroughly mixed prior to use and must be used before the mixture solidifies. The liquid coating forms a film by solvent evaporation and continued chemical reaction between the epoxy resin and the curing agent. The "pot life" is different for each unique formulation. Commonly used coatings have pot lives that range from 2 to 8 hr at 25°C (77°F). Coal tar epoxy films have high chemical resistance, easily form thick films, and have a high dielectric strength. The high dielectric strength makes them particularly suitable for use near anodes in cathodic protection systems, where the high current densities can damage other types of coatings. Coal tar epoxy coatings are known to exude low-molecular-weight fractions (ooze solvent), which cause recoating problems. The U.S. Navy limits the use of coal tar and coal tar epoxy coatings to protect workers from the possibility of low levels of carcinogens in the refined coal tar.

Coal tar epoxies are also commonly used on fresh-water barges. Other suitable paints are available, but the coal tars are the least expensive.

2.2.1.1.4 Epoxy.[9] Epoxy coatings for marine applications are typically formed by the chemical reaction of a bisphenol-A-type epoxy resin with a "curing agent" (e.g., amines, amine adducts, or polyamide resins). The coatings are packaged with the epoxy portion in one container and the curing agent in a second container. As with coal tar epoxy systems, the coatings must be used within their pot life. Commonly used epoxy coatings have pot lives that range from 2 to 8 hr at 25°C (77°F). Epoxy coatings typically dry to touch within 3 hr and are fully cured after 7 days at 25°C (77°F). The time to cure depends on the catalyst, ambient and surface temperature during the curing period. The curing reaction slows down markedly at temperatures below 10°C (50°F).

Epoxy coating films are strongly resistant to most chemicals and make excellent anticorrosion coatings. They are one of the principal materials used to control corrosion in the marine environment and are used in many primers and topcoats. However, epoxy coatings chalk when exposed to intense sunlight. For this reason, epoxy coatings are often used with cosmetic topcoats (e.g., silicone alkyds) that are more resistant to sunlight.

2.2.1.1.5 Inorganic zinc.[9] Inorganic zinc coatings consist of powdered zinc metal held together by a binder of inorganic silicates. The binder is formed by the polymerization of sodium silicate, potassium silicate, lithium silicate, or hydrolyzed organic silicates. The liquid coating forms a film by the evaporation of the solvent medium (water and/or VOC's), followed by the chemical reactions between the silicate materials, zinc dust, and curing agents. Oxygen molecules are adsorbed in the film matrix in the case of water borne zinc coatings.

A variety of curing mechanisms are used to form the final inorganic zinc coating film. The coatings are frequently packaged as multicomponent paints. All parts must be mixed thoroughly before being applied. After mixing, inorganic zinc coatings have a pot life of 4 to 12 hr. The solvent material must evaporate from these coatings before they can form a film. For solvent borne, self cure, inorganic zincs, some water is needed to allow the binder to cure. Low humidity can retard cure rate.

Because the coatings consist primarily of zinc, they offer extraordinary galvanic corrosion protection. At the same time for a variety of reasons, they can be corroded by the same environments that damage zinc. Inorganic zinc coatings are often used on weather (exterior) decks and as primers for the ship superstructure (above waterline).

2.2.1.1.6 <u>Organic zinc</u>.[9] Organic zinc coatings use zinc as a pigment in a variety of organic binders. The primary feature of organic zinc coatings is that the coating film is electrochemically active and reacts to provide cathodic protection to the steel substrate. These coatings are not as mechanically durable or as resistant to high temperatures as the inorganic zinc coatings. However, they are frequently more compatible with organic topcoats. Generally, these coatings are more tolerant of application variables than are inorganic zinc coatings. The drying and curing properties of this type of coating are determined by the properties of the binder. These coatings are not recommended for immersion service in salt water for the same reason given for inorganic zinc coatings, namely, that they can be corroded by the same environments that damage zinc.

2.2.1.1.7 Polyurethane.[9] Polyurethane marine coatings are made from resins that contain complex monomers that incorporate isocyanate chemistry, which is highly reactive with hydroxyl groups (e.g., water and alcohols), which are commonly used as curing agents. Coating films are formed in two overlapping steps by solvent evaporation followed by a chemical reaction between the polyurethane resin and the curing agents. The most commonly used polyurethane marine coatings are packaged as two- or three-component systems. One component contains the polyurethane resin, and the second component contains an organic polyol. Some systems require the use of a third component containing catalysts (e.g., metallic soaps or amine compounds) to accelerate curing.

Polyurethane coatings form tough, chemically-resistant coatings and make particularly good high-gloss cosmetic finishes. They have good abrasion and impact resistance and are particularly useful in high-wear areas. They have good weather resistance but lose gloss when exposed to intense sunlight. Weathered polyurethane coatings are often difficult to recoat, and subsequent topcoats will not adhere unless special care is taken to prepare the surface before repainting aged or damaged areas. Polyurethane coatings are most commonly used as topcoats, e.g., in a coating system consisting of one coat inorganic zinc, one coat high-build epoxy, and one coat aliphatic polyurethane. These coatings are used in the areas above the waterline such as the topside, weather deck, and superstructure areas.

2.2.1.1.8 Spray-metallized coatings.[9] Spray-metallized coatings are formed by melting a metal and spraying it onto the surface to be protected. The metal solidifies in place and forms a tightly adhering barrier to protect against corrosion. Zinc and aluminum are the most commonly used metals for spray-metallizing. Aluminum is generally favored for marine service because of its longer service life and low weight. It is generally necessary to topcoat the sprayed metal coating to improve appearance and protect the metallized coating to gain the maximum possible service life. Vinyl or epoxy coatings are typically used as topcoats for aluminum metal spray coatings.

2.2.1.1.9 Vinyl coatings.[9] Vinyl resins are formed by the polymerization of vinyl compounds. The most common resins are based on polyvinyl chloride (PVC) copolymers. These resins form films by solvent evaporation. Freshly applied coatings are dry to the touch within 1 hr and are fully dried within 7 days. Vinyl coatings are particularly useful where fast drying, particularly at low temperatures (0° to 10°C [32° to 50°F]), is required.

Coatings based on vinyl polymers perform well in immersion situations and are frequently used to protect submerged structures such as the underwater hull of a ship. These coatings have excellent resistance to many chemicals and are good weather-resistant materials. Vinyl coatings are softened by heat and are not suitable for sustained use above 66°C (150°F). Vinyl paint systems require the use of a thin coat of wash primer (containing acids to etch the surface) as the first coat to ensure good adhesion to steel.[9]

2.2.1.2 Paint Solvents.[10] The solvent component of marine paints is a transient ingredient, but its quality and suitability are apparent for the life of the coating. Choice of solvents affects coating film integrity, appearance, and application. Thus, solvents play an important role in film formation and durability even though they are not a permanent component. The solvent in most paints is a mixture of two or more chemical compounds that impart different properties to the solvent blend.

Two basic performance properties must be considered in selecting the proper solvent for marine coatings: solvent power and evaporation rate. Solvency refers to a solvent's ability to dissolve the resin and reduce its viscosity so the paint can be applied. The solubility of the resin and the solvency of the solvent determine initial coating viscosity. Evaporation is subsequently necessary as part of the drying process and in controlling the paint viscosity at various stages of drying (film viscosity increases as the solvent evaporates). The solvent must evaporate relatively quickly during initial drying to prevent excessive flow (sagging of the wet paint film), but in later stages it must evaporate slowly enough to give sufficient leveling and adhesion. Different solvent components are typically used to achieve such evaporative performance.

Table 2-4 lists the most common organic solvents used at shipyards based on the collected Section 114 information in the data base.[5] The predominant solvents used in marine paints and in their associated cleaning are obtained from petroleum (crude oil). Many of the commonly known solvents are actually petroleum distillation fractions and are composed of a number of compounds. Distillation fractions are typically distinguished as aliphatic or aromatic.

TABLE 2-4. TYPICAL SOLVENTS USED IN MARINE PAINTS[5]

Xylene	Isopropyl alcohol
Toluene	Butyl alcohol
Ethyl benzene	Ethyl alcohol
Methyl ethyl ketone	Methyl amyl ketone
Methyl isobutyl ketone	Acetone
Ethylene glycol ethers	Propylene glycol ethers
Mineral spirits[a]	
High-flash naphtha[b]	
Hexane	

[a] Ligroine (light naphtha), VM&P naphtha, Stoddard solvent, and certain paint thinners are also commonly referred to as mineral spirits.

[b] Specifications for this material exist under ASTM D3734-91.

Aliphatic petroleum solvents are distillation products from crude oil and are characterized by relatively low solvent power, relatively low specific gravities, and bland odors. Typical aliphatic petroleum solvents include hexane, mineral spirits, varnish makers' and painters' (VM&P) naphtha, Stoddard solvent, and kerosene.

Aromatic petroleum solvents may be produced from aliphatic compounds. There are only four commonly used aromatic solvents in the coatings industry: xylene, toluene, medium-flash naphtha, and high-flash naphtha. Aromatics are stronger solvents than are aliphatics; they dissolve a wider variety of resins.

2.2.1.3 Coating Systems. In general, the coating systems described in this section are based on those used by the U.S. Navy and may not be representative of those used by commercial vessels with different (and perceived less stringent), service requirements. Coating system selection requires consideration of many different factors, including:

1. Service requirements of the coated surfaces;
2. Materials and application costs;
3. Temperature and humidity during application and drying/curing;
4. Surface preparation requirements;
5. Desired service life;
6. Accessibility of the area for maintenance;[11] and
7. Life-cycle costs.

Coating system requirements can be broken down into several generalized categories based upon the ship's structural components. These structural components include the freeboard areas and other exterior surfaces above the waterline (boot top) area; exterior deck areas; interior habitability spaces; fuel, water, ballast, and cargo tanks; and the underwater hull areas. These basic areas of a typical ship are illustrated in Figure 2-2. This figure and the following discussion were taken from a letter from S. D. Rodgers of the Naval Sea Systems Command to A. Bennett of EPA involving protective coatings for U.S. Naval ships.[7] The remainder of this section provides information on coating systems that have been identified to provide optimum service performance for various ship components.

2.2.1.3.1 Freeboard areas and exterior surfaces above the boot top area. The ship's exterior superstructure is subject to acidic fumes, extreme temperatures ranging from those of the tropics to those of the Arctic, intense sunlight, thermal shock when cold rain or sea spray contacts hot surfaces, and attack of wind-driven saltwater and spray. A two- or three-part system is recommended for these surfaces above the waterline. The anticorrosion protection is provided by zinc-rich coatings and/or epoxy-polyamide coatings. Cosmetic color and durability are provided by a silicone-alkyd, acrylic-modified, two-component epoxy, polyurethane, or acrylic topcoat. Typical paint systems use either a two-coat epoxy with a two-coat silicone alkyd or a one-coat, zinc-rich primer with a three-coat epoxy and a two-coat silicone alkyd.

2.2.1.3.2 Exterior deck areas. Decks, in addition to being in contact with seawater, are subject to the wear caused by foot and/or vehicular traffic, mechanical abrasion, fuel and chemical spills, and in the case of landing decks, the landings and take-offs of aircraft. Antislip deck coatings are used to provide a rough surface to help avoid uncontrolled motion of the crew and machinery on wet, slippery decks. Antislip coatings need to be selected for both their mechanical roughness and their resistance to lubricants and cleaning compounds used on the decks. The most durable antislip coatings are based on epoxy coatings that contain coarse aluminum oxide grit. A typical antislip coating system may consist of one coat of epoxy primer and one coat of epoxy nonskid coating.

2.2.1.3.3 Interior habitability spaces. Interior habitability areas suffer from high humidity, abrasion, cooking fumes, soiling, fires, and heat. Nonflaming and intumescent coatings are the two major types of fire safety coatings used. Nonflaming coatings prevent the spread of fire, and intumescent coatings are used to reduce heat damage to surfaces that are exposed to fire. Common nonflaming coatings are based on chlorinated alkyd resins and on water emulsions of chlorinated polymers. Intumescent coatings contain materials that expand (foam) when heated and create a thick insulation film (char) that retards damage to the substrate. Typical applications involve the use of alkyd primers under chlorinated alkyd or waterborne nonflaming coatings (e.g., one coat alkyd, two coats chlorinated alkyd).

2.2.1.3.4 Tanks. Often cargo spaces and tanks are in a more varied, and in some cases, more chemically reactive environment than the hull. The cargo/tank coatings must resist seawater, potable (drinking) water, hydrocarbon fuels and lubricants, sanitary wastes, and chemical storage and spills. Coating requirements for potable water tanks are vastly different from those for fuel or ballast tanks. Fuel tank coatings must prevent contamination of the fuel by corrosion products or by materials in the coatings. They must also prevent corrosion damage to the tank and be resistant to aliphatic and aromatic petroleum products. A three-coat epoxy system is satisfactory for this use. Zinc coatings are not used in fuel tanks because zinc dissolved into the fuel, particularly gasoline, can cause serious damage to engines.

Coatings for potable water tanks must prevent contamination of the potable water by corrosion products and must not contribute objectionable smell or taste to the water. The coatings must not react with halogen compounds (e.g., bromine or chlorine) used to disinfect the water. Care must be taken to avoid the use of phenolic compounds in any coating used for potable water tanks. (Phenolic compounds are sometimes added to epoxy coatings to accelerate curing.) Halogenated phenolic compounds in concentrations as low as 1 part per trillion can make drinking water unfit for use.

Ballast tanks are exposed to both total immersion and partial immersion in seawater, but marine fouling is typically not a problem. The upper parts of the tank are constantly exposed to high humidity, condensation, and salt, while the lower portions are constantly immersed. However, the continually immersed areas can be protected by a combination of cathodic protection and barrier coatings. Other portions of the tanks can be protected with barrier coatings. A typical coating system may consist of two or three coats of epoxy.

2.2.1.3.5 Underwater hull areas. The underwater hull is in constant contact with seawater and must resist the ravages of impact abrasion, galvanic corrosion, and cavitation. Exterior underwater areas also need protection from the attachment of marine organisms, known as fouling. This portion of ships and structures are inaccessible for routine maintenance, and the coatings chosen must give reliable performance for extended periods of time. Corrosion control for underwater areas usually includes cathodic protection using sacrificial anodes (zinc or aluminum) or impressed current cathodic protection systems. Cathodic protection systems generate strongly alkaline environments near the anodes and in areas where damage exposes metal to the water. Both corrosion control and antifouling coatings must be resistant to the environment created by cathodic protection.

2.2.1.4 Marine Specialty Coating Categories. A number of marine specialty coating categories were adopted by the California Air Resources Board (CARB) in 1990. All other marine coatings were classified as "general use" coatings and are subject to a single regulation. A description of the specialty coating categories is given in this section because the paint categories used for this project were based on them. Figure 2-3 shows that all specialty coatings (including antifoulants and inorganic zinc) account for 31 percent of total marine coatings used at U.S. shipyards in the project data base[5]. Specialty categories are based primarily on their functions (e.g., an antifoulant's function is to prevent the hull from fouling). To satisfy these functions, a variety of resins/chemistries may be used. Therefore, the paints in a specialty category may not easily be substituted for one another. The whole paint system may have to be changed to ensure compatibility.

Specific paint categories referred to as specialty were defined by CARB after a number of discussions with industry representatives indicated that a general VOC limit on all marine coating categories was not technologically feasible in meeting the performance requirements for marine vessels.[11] Higher VOC limits for these specialty coating categories were adopted by

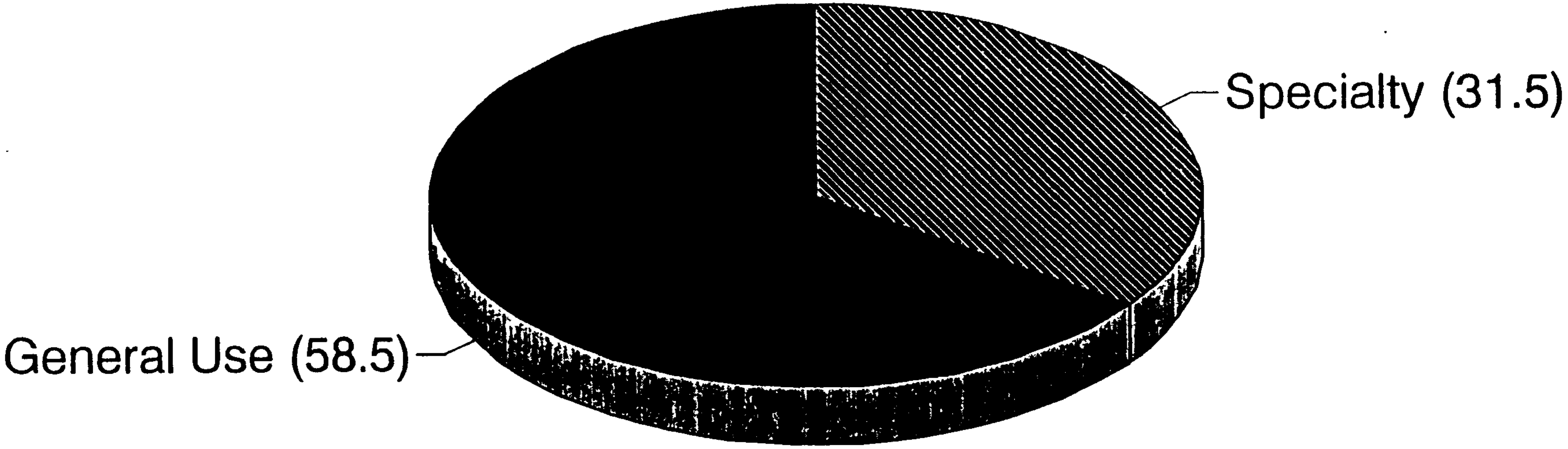

Figure 2-3. Shipyard paint usage-by overall category.[5] (Based on project data base)

CARB to take into account the performance requirements of each category. A description of each of the adopted specialty paint categories is given below.

2.2.1.4.1 Air flask coatings. Air flask coatings are special combustion coatings applied to interior surfaces of high pressure breathing air flasks to provide corrosion resistance and which are certified safe for use with breathing air supplies.

2.2.1.4.2 Antenna coatings. Antenna coatings are applied to equipment which is used to receive or transmit electromagnetic signals.

2.2.1.4.3 Antifoulant coatings. Antifoulant coatings are applied to the underwater portion of a vessel to prevent or reduce the attachment of biological organisms. They are required to be registered with EPA as pesticides.

2.2.1.4.4 Heat resistant coatings. Heat resistant coatings are used on machinery and other substrates that during normal use must withstand high temperatures of at least 204°C (400°F). These coatings are typically silicone alkyd enamels.

2.2.1.4.5 High gloss coatings. High-gloss coatings achieve at least 85 percent reflectance on a 60 degree meter when tested by ASTM Method D-523. These coatings are typically used for marking safety equipment on marine vessels.

2.2.1.4.6 High temperature coatings. High temperature coatings are coatings which during normal use must withstand temperatures of at least 426°C (800°F).

2.2.1.4.7 Inorganic zinc coatings. Inorganic zinc coatings contain elemental zinc incorporated into an inorganic silicate binder, used for the express purpose of providing corrosion protection.

Although water-based, zinc-rich primers have recently been made available from nearly every major manufacturer, field testing in a variety of services has not been completed. Failure of a primer is considered to be more catastrophic than the failure of a topcoat because it results in exposure of bare metal.

2.2.1.4.8 Nuclear (low-activation interior) coatings. Nuclear coatings are protective coatings used to seal porous surfaces such as steel (or concrete) that otherwise would be subject to intrusion by radioactive materials.

2.2.1.4.9 Military exterior coatings. Military exterior coatings are exterior topcoats applied to military vessels (including U.S. Coast Guard) which are subject to specified chemical, biological, and radiological washdown requirements.

2.2.1.4.10 Mist coatings. Mist coatings are thin film epoxy coatings up to 2 mil (0.002 in.) thick (dry) applied to an inorganic or organic zinc primer to promote adhesion of subsequent coatings.

2.2.1.4.11 Navigational aids coatings. Navigational aids coatings are applied to Coast Guard buoys or other Coast Guard waterway markers when they are recoated at their usage site and immediately returned to the water.

2.2.1.4.12 Nonskid coatings. Nonskid coatings are specially formulated for application to the horizontal surfaces aboard a marine vessel, which provide slip resistance for personnel, vehicles, and aircraft.

2.2.1.4.13 Organic zinc coatings. Organic zinc coatings are derived from zinc dust incorporated into an organic binder which is used for the express purpose of corrosion protection.

2.2.1.4.14 Pretreatment wash primer coatings. Pretreatment wash primer coatings contain a minimum of 0.5 percent acid by weight and are applied directly to bare metal surfaces to provide necessary surface etching.

2.2.1.4.15 Repair and maintenance thermoplastic coatings. Repair and maintenance thermoplastic coatings have vinyl, chlorinated rubber, or bituminous (coal tar)-based resins and are used for the partial recoating of in-use non-U.S. military vessels, applied over the same type of existing coatings. Coal tar epoxies are not included in this category even though they are bituminous-based; they were determined to better fit the epoxy (general use) category.

2.2.1.4.16 Rubber camouflage coatings. Rubber camouflage coatings are specially formulated epoxy coatings, used as a camouflage topcoat for exterior submarine hulls and sonar domes lined with elastomeric material, which provide resistance to chipping and cracking of the rubber substrate.

2.2.1.4.17 Sealant coat for wire sprayed aluminum. A sealant coat for wire sprayed aluminum coating is a coating of up to one mil (0.001 inch) in thickness of an epoxy material which is reduced for application with an equal part of an appropriate solvent used on wire-sprayed aluminum surfaces.

2.2.1.4.18 Special marking coatings. Special marking coatings are used on surfaces such as flight decks, ships' numbers, and other safety or identification applications.

2.2.1.4.19 Specialty interior coatings. Specialty interior coatings are extreme-performance coatings with fire-retarding properties that are required in engine rooms and other interior surfaces aboard ships. They are generally single-component alkyd enamels.

2.2.1.4.20 Tack coats. Tack coats are epoxy coats up to two mils thick applied to allow adhesion to a subsequent coating where the existing epoxy coating has dried beyond the time limit specified by the manufacturer for the application of the next coat.

2.2.1.4.21 Undersea weapons systems coatings. Undersea weapons systems coatings are applied to any component of a weapons system intended for exposure to a marine environment and intended to be launched or fired undersea.

2.2.1.5 Application Equipment. This section discusses the paint application methods generally used to apply coatings to marine vessels. These methods include:

1. Conventional air-atomized spraying;
2. Airless spraying;
3. Air-assisted airless spraying;
4. High-volume, low-pressure (HVLP) spraying;
5. In-line heaters (hot spraying) in conjunction with other spray equipment;

6. Brushing; and
7. Rolling.

Of these methods, the most popular techniques used at shipyards include brushing, rolling, conventional air-atomized spraying, and airless spraying. Brushing and rolling are primarily used for touchup and recessed surfaces where spraying is not practical. Spraying is primarily used for all other surfaces because of its high application speed.

Spray paint application systems include three basic components: a container that holds the paint, a pressurized propelling system, and a paint gun. A brief summary of the various spray application systems is provided in Table 2-5.[12]

2.2.2 Thinning Solvents

Solvents are frequently added to coatings by the applicator just prior to spraying to adjust viscosity. The volume of VOC emissions from "paint thinning" is second only to that from paint solvents. Thinning is done at most shipyards (regardless of size) even though the paint manufacturers typically state it is usually unnecessary.[5,6] Weather conditions also play a part in thinning in northern locations during the winter months when the cold temperatures increase paint viscosity.

2.2.3 Cleaning Solvents

Solvents used to clean spray guns and other equipment and to prepare surfaces prior to painting are referred to as cleaning solvents. As mentioned previously, emissions from cleaning solvents were addressed in an ACT published by EPA on Industrial Cleaning Solvents. Cleaning solvents must be compatible with solvents in the various marine paints to be effective. A wide range of practices and/or systems is used for spray equipment cleaning. Methods range from spraying solvent through a gun into the air (or a bucket) to using a totally enclosed system where the spray gun is mounted. Several shipyards recycle used solvents in-house, and many others (especially the major yards) are required to dispose of the used solvent as a hazardous material.[5]

Figure 2-4 and Table 2-6 give the breakdown of solvent usage

TABLE 2-5. ADVANTAGES AND DISADVANTAGES OF SPRAY PAINT APPLICATION METHODS[12]

Advantages	Disadvantages
Conventional air-atomized spray	
Low equipment and maintenance costs Excellent material atomization Excellent operator control Quick color change capabilities Coating can by applied by syphon or under pressure	Uses high volume of air Does not adapt to high-volume material output Low transfer efficiencies Can cause contamination and worker visibility problems
Airless spray	
Most widely used Low air usage (uses hydraulic pressures) High-volume material output Limited overspray fog Large spray patterns and high application speeds Application of heavy viscous coatings Excellent for large surfaces Good transfer efficiency on large surfaces	Uses high volume of air Expensive fluid tips High equipment maintenance Difficult to mix some high viscosity materials Minimum operator control during application System not very flexible Not suitable for high-quality surface appearance Pressurized system can cause injuries to operator if not used with adequate caution
Air-assisted airless spray	
Low coating usage Fair to good operator control on air pressure Few runs and sags in painted surface Good atomization	High equipment maintenance Expensive fluid tips Poor operator control on fluid pressure Not suitable for high-quality surface appearance
High-volume, low-pressure (HVLP) spray	
Low blowback and spray fog Good transfer efficiency Portable (totally self-contained equipment) Easy to clean Overall time and cost savings Can be used for intricate parts Good operator controls on the gun	High initial cost Slower application speed (controversial) Does not finely atomize some high-solids coating materials (controversial) High cost for turbine maintenance Requires more operator training than conventional Still relatively new on the market Some very high solids products not sprayable by HVLP
In-line heaters	
Reduces the need for solvent additions for viscosity reduction Application viscosity is not altered by ambient temperature and weather conditions High film build with fewer coats; smoother surfaces Potential for improved transfer efficiency Several designs available Can be used in conjunction with most types of spray equipment	Additional maintenance and equipment costs Fast solvent flash-off can develop pinhole and solvent entrapment if coating is applied too heavily Requires additional fluid hose to spray gun for recirculating Not recommended for premixed two-component coatings Not intended for water-based coatings
Brushing	
Primarily used for touch-up jobs and in small work areas	Labor-intensive
Rolling	
Manual application used on larger areas where overspray presents cleaning difficulties	May not be appropriate for some primers (does not penetrate surface)

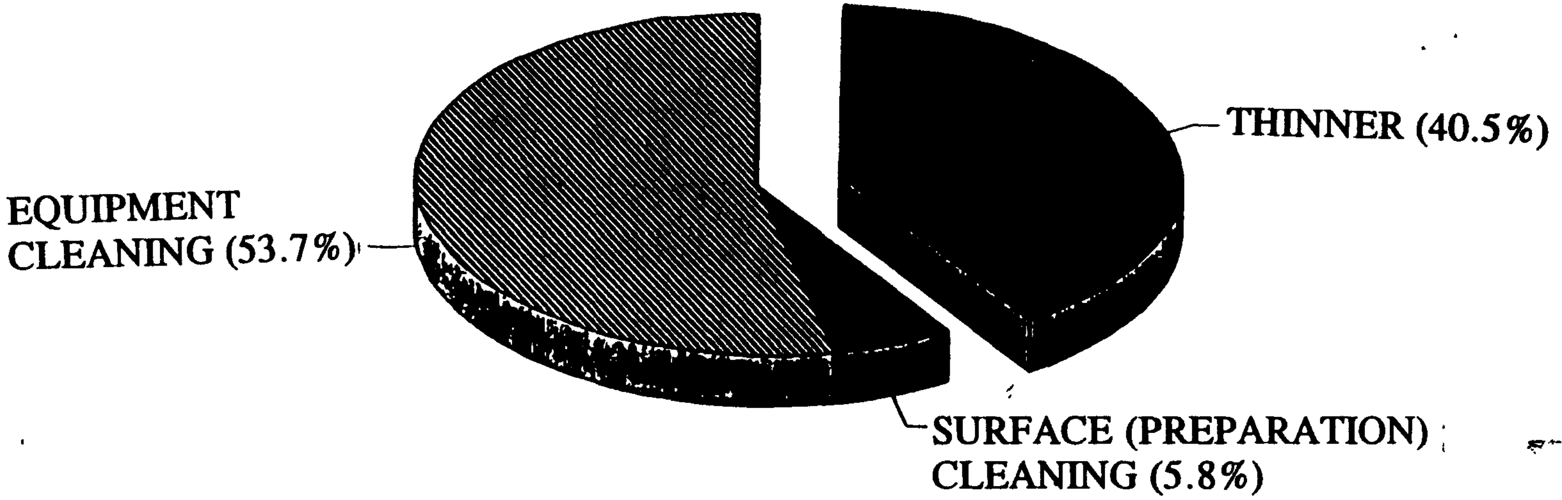

Figure 2-4. Shipyard solvent usage.[5]

and the average density of each solvent type. Solvents used for surface preparation have been included here because of the very low usages reported and actual shipyard practices (all solvents are usually stored/collected together). In general, all major solvent uses at shipyards (solvents used for thinning, equipment cleaning, and surface preparation cleaning) are the same in terms of the VOC's used.

TABLE 2-6. SOLVENT USAGE BREAKDOWN[5]

Use description	Total usage, L (gal)	Average density, g/L (lb/gal)
Thinner	514,739 (135,980)	838.8 (6.99)
Cleaning to prepare surfaces	73,433 (19,399)	842.4 (7.02)
Cleaning of Equipment and other items	683,030 (180,438)	846.0 (7.05)
Total combined	1,271,202 (335,817)	842.4 (7.02)

2.2.4 Abrasive Blasting

This section provides information on abrasive blasting media used for preparing surfaces for painting and abrasive blasting methods.

2.2.4.1 General. The abrasive blasting process is used to prepare the surface (remove rust and deteriorated coatings) to ensure adhesion and performance of a new anticorrosive or antifouling system. Below the waterline on the hull, blasting removes marine growth, algae, and barnacles that reduce ship speed, increase fuel consumption, and increase noise as the ship travels.

The quality of surface preparation is the greatest single factor that will affect performance of the new coating system. Blast cleaning is the most effective and the preferred method of preparing metallic surfaces. Wire brushes, sanders, and other alternative means of surface preparation are less effective than blasting and can lead to early coating failure because they do not provide the optimum surface profile and/or cleanliness to which the new coating must adhere.[8]

2.2.4.2 Types of Abrasives. Abrasive blast materials are generally classified as sand, metallic shot or grit, or other. The cost and properties associated with the abrasive material dictate choice of use.

Sand is the least expensive blast material but presents some safety concerns. It is commonly used when blasting outdoors where reclaiming is not feasible. Sand has a rather high breakdown rate (frets easily), which can generate substantial dust and causes health and safety concerns involving silicosis. For this reason, its use in most shipyards is limited. Synthetic abrasives, such as silicon carbide and aluminum oxide, are becoming popular substitutes for sand. Although the cost of these synthetic abrasives is three to four times that of sand, they are more durable and create less dust. Synthetic materials are predominantly used in blasting enclosures and in some unconfined blasting operations where abrasive materials can be readily reclaimed.

Metallic abrasives are made from cast iron and steel. Cast iron shot is hard and brittle and is made by spraying molten cast iron into a water bath. Cast iron grit is produced by crushing the oversized and irregular particles formed in manufacturing cast iron shot. Steel shot is produced by blowing molten steel. Steel shot is not as hard as cast iron shot but is much more durable. Due to the higher costs associated with metallic abrasives, they are predominantly used in specially designed enclosures with reclaiming equipment.

Glass beads, crushed glass, cut plastics, and nutshells are included in the "other" category. As with synthetic and metallic abrasive materials, they are generally used in operations where the material is readily reclaimed.

The type of abrasive used in a particular application is usually specific to the blasting method. Dry abrasive blasting is usually done with sand, aluminum oxide, silicon carbide, metallic grit, or shot. Wet blasting is usually done with sand, glass beads, or any materials that will remain suspended in water. Table 2-7 lists common abrasive materials and their applications.[13,14] The choice of abrasive also is influenced by considerations of the abrasive cost at the blasting site, the labor plus material cost for cleaning a unit area of hull, the costs of cleaning and disposal of a particular abrasive, and the desired surface profile. Table 2-8 provides the compositions of some commonly used blast media.[15]

2.2.4.3 Abrasive Blasting Systems. Typically, blasting media is analogous to spraying paint. Blasting systems require a reservoir for the blast media, a propelling device, and a nozzle. The exact equipment used depends on the application.

The three propelling methods used are centrifugal wheels, air pressure, and water pressure. Centrifugal wheel systems depend on centrifugal and inertial forces to mechanically throw or propel the abrasive media at the substrate.[16] Compressed air systems blast the abrasive at the substrate. Finally, the water blast method uses either compressed air or high-pressure water.[17] The most popular systems are those that use either air pressure or water pressure to propel the abrasive material. Therefore, only these methods are described.

The "compressed air suction," the "compressed air pressure," and the "wet abrasive blasting" systems use air to create the driving force for propelling the abrasive material out of the gun. Hydraulic blasting systems use water to create this driving force.

Compressed air suction systems include two rubber hoses that are connected to the blasting gun. One delivers air from the compressed-air supply, and the other delivers media from the abrasive supply tank or "pot." The gun (Figure 2-5) consists of an air nozzle that discharges into a larger nozzle. The high-velocity air jet (expanding into the larger nozzle) creates a partial vacuum in the chamber. This vacuum draws the abrasive into the outer nozzle and expels it through the discharge

TABLE 2-7. MEDIA COMMONLY USED IN ABRASIVE BLASTING[13,14]

Type of medium	Sizes normally available	Applications
Glass beads	8 to 10 sizes from 30 to 440 mesh; also many special gradations	Decorative blending; light deburring; peening; general cleaning; texturing; noncontaminating applications
Aluminum oxide	10 to 12 sizes from 24 to 325 mesh	Fast cutting; matte finishes; descaling and cleaning of coarse and sharp textures
Garnet	6 to 8 sizes (wide-band screening) from 16 to 325 mesh	Noncritical cleaning and cutting; texturing; noncontaminating for brazing steel and stainless steel
Crushed glass	5 sizes (wide-band screening) from 30 to 400 mesh	Fast cutting; low cost; short life; abrasive; noncontaminating applications
Steel shot	12 or more sizes (close gradation) from 8 to 200 mesh	General-purpose rough cleaning (foundry operation, etc.); peening
Steel grit	12 or more sizes (close gradation) from 10 to 325 mesh	Rough cleaning; coarse textures; foundry welding applications; some texturing
Cut plastic	3 sizes (fine, medium, coarse); definite-size particles	Deflashing of thermoset plastics; cleaning; light deburring
Crushed nutshells	6 sizes (wide-band screening)	Deflashing of plastics; cleaning; very light deburring; fragile parts

TABLE 2-8. COMPOSITIONS OF BLAST MEDIA[15]

Trade or common name	Composition
Natural sand	Essentially pure silicon dioxide
Green Diamond	Copper slag containing residues of free silica, lead, nickel, and chromium
Polygrit	Cuprous slag
Boiler slag	Silica containing iron oxide, alumina, and traces of magnesium, calcium, copper, lead, tin, antimony, and arsenic oxides
Dolcite Porphyry	Igneous crushed rock
Black Diamond	Iron slag containing silica, iron, aluminum, calcium, magnesium and titanium oxides, sulfates, phosphorus, manganese and carin

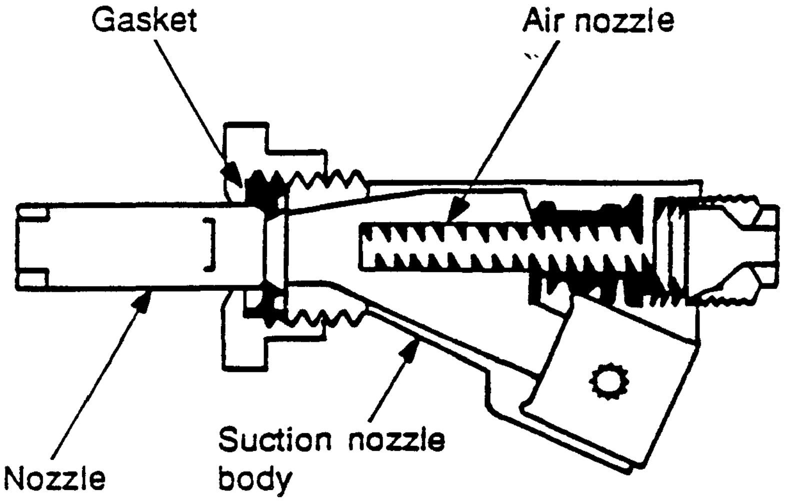

Figure 2-5. Suction blast nozzle assembly.[17]

opening. Figure 2-6 shows a typical suction-type blasting machine.

Figure 2-7 illustrates the compressed air pressure system. Pressure in the tank forces abrasive through the blast hose rather than siphoning it, as in the suction-type system. The compressed air line is connected to both the top and bottom of the pressure tank. This allows the abrasive to flow by gravity into the discharge hose without loss of pressure (see Figure 2-7).

Finally, wet abrasive blasting systems (Figure 2-8) propel a mixture of abrasive and water with compressed air. (An alternate method uses a pressure tank and a modified abrasive blasting nozzle, Figure 2-9.)

Figure 2-10 illustrates the nozzle used for yet another blast scheme. Hydraulic blasting incorporates a nozzle similar to that of air suction systems. High-pressure water is used instead of compressed air as the propelling force.

Pressure blast systems generally give a faster, more uniform finish and use less air than do suction blast systems. Pressure blast systems can operate at as low as 1 pound per square inch (psig) to blast delicate parts and up to 125 psig to handle the most demanding cleaning and finishing operations.[14]

Suction blast systems are generally selected for light to medium production requirements, limited space, and moderate budgets. Since the suction blast systems use open-top reservoirs, it is unnecessary to stop blasting to change the abrasive or refill the supply tank.[13,14]

2.3 BASELINE EMISSIONS

2.3.1 VOC Emissions

Figure 2-11 shows the annual usage breakdown of all marine paint categories. Table 2-9 gives the average of the reported solvent VOC contents for specialty and general use categories, respectively (weighted by volume).[5] Using these average values which assume that all "as supplied" paint solvents and thinners are emitted, VOC emissions on a per-gallon basis are then calculated for each paint and thinning solvent category. These

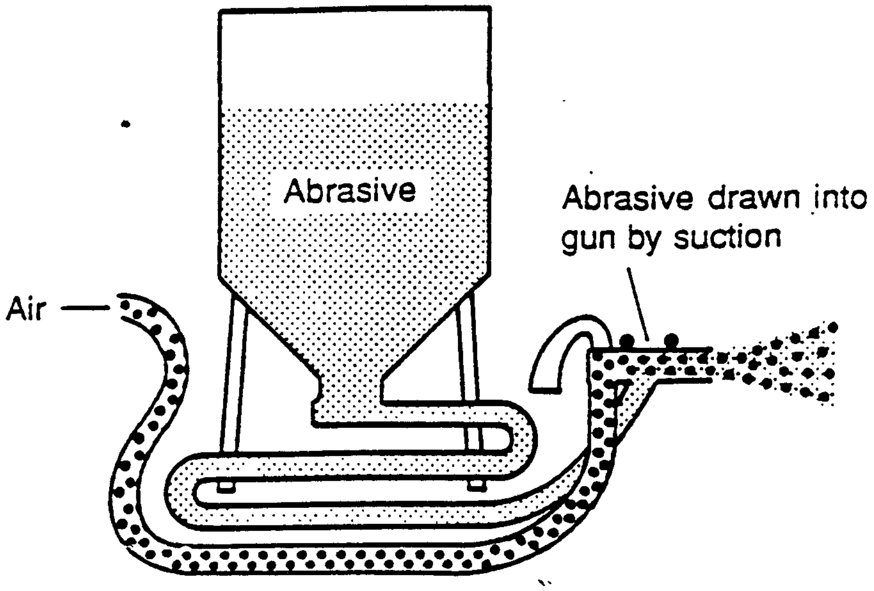

Figure 2-6. Suction-type blasting machine.[17]

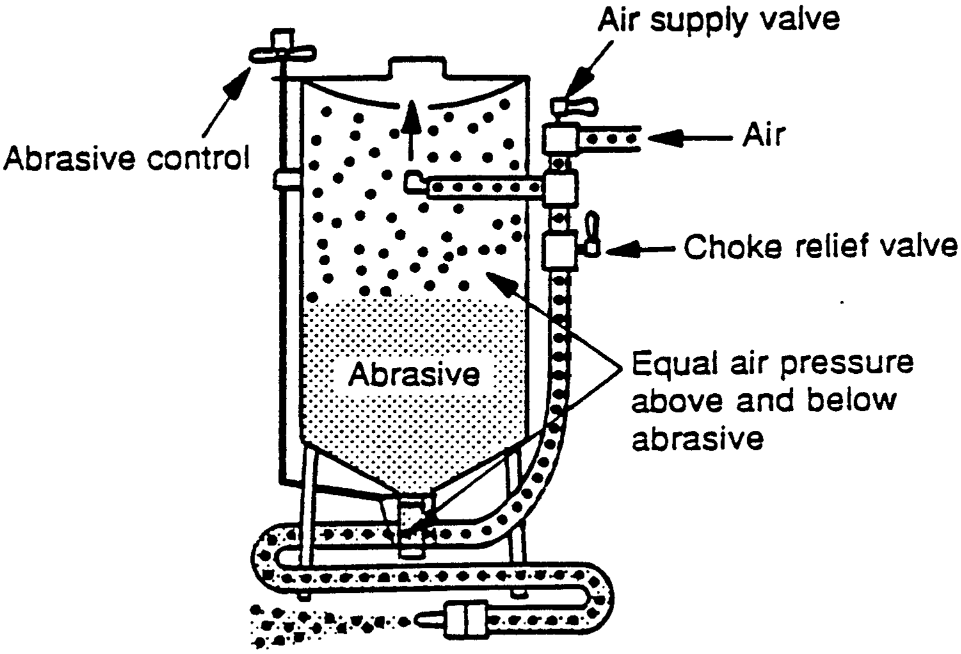

Figure 2-7. Pressure-type blasting machine.[13]

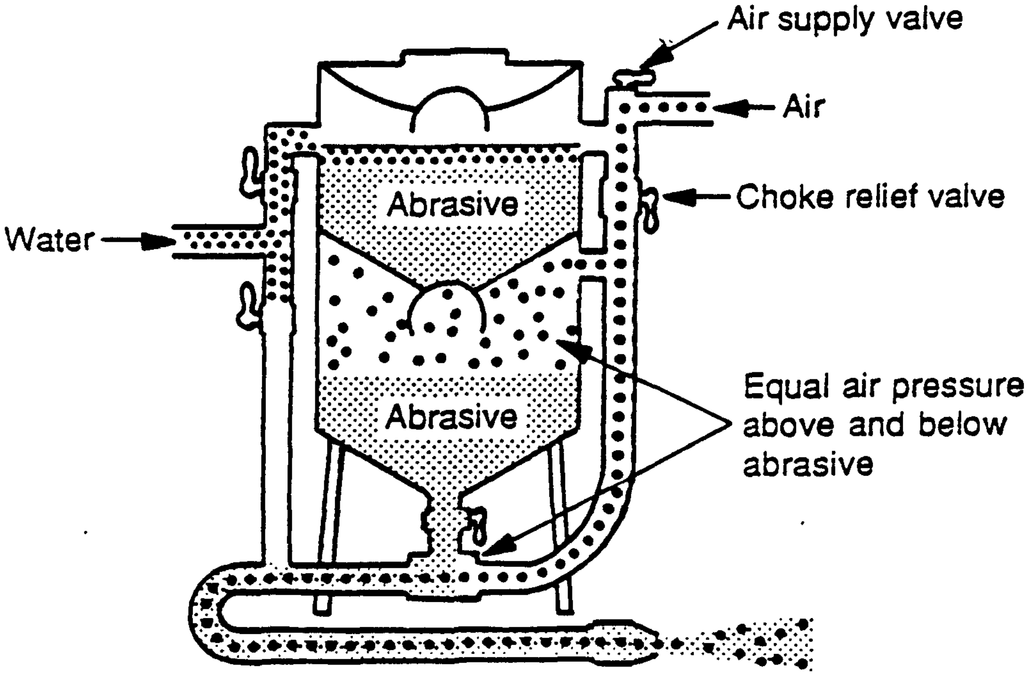

Figure 2-8. Wet blasting machine.[13]

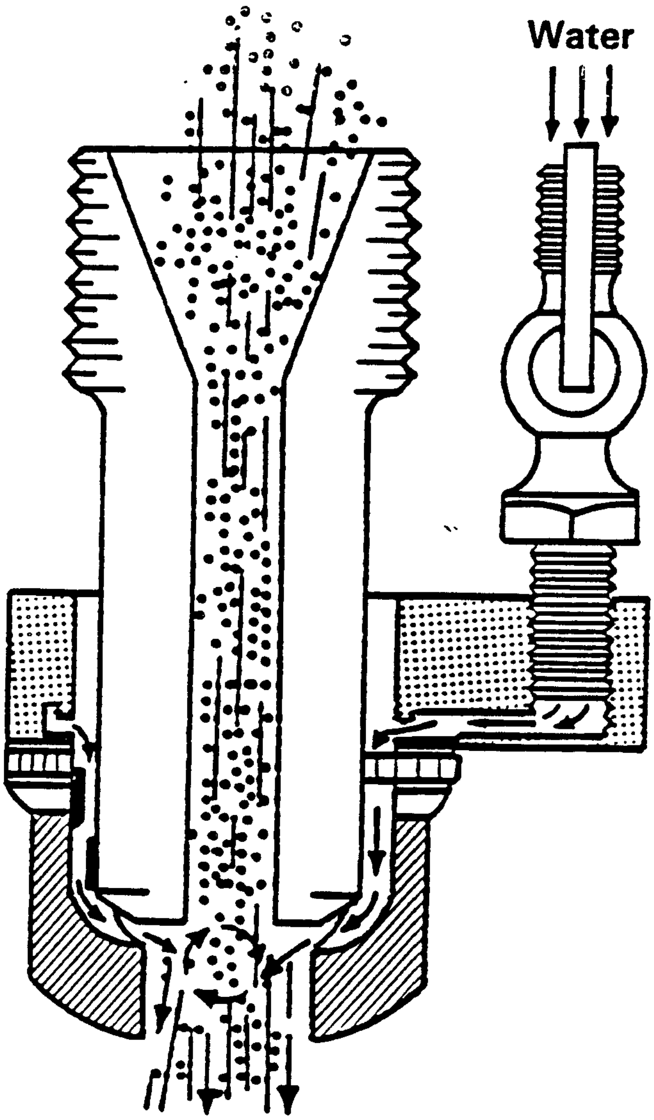

Figure 2-9. Adapter nozzle converting a dry blasting unit to a wet blasting unit.[13]

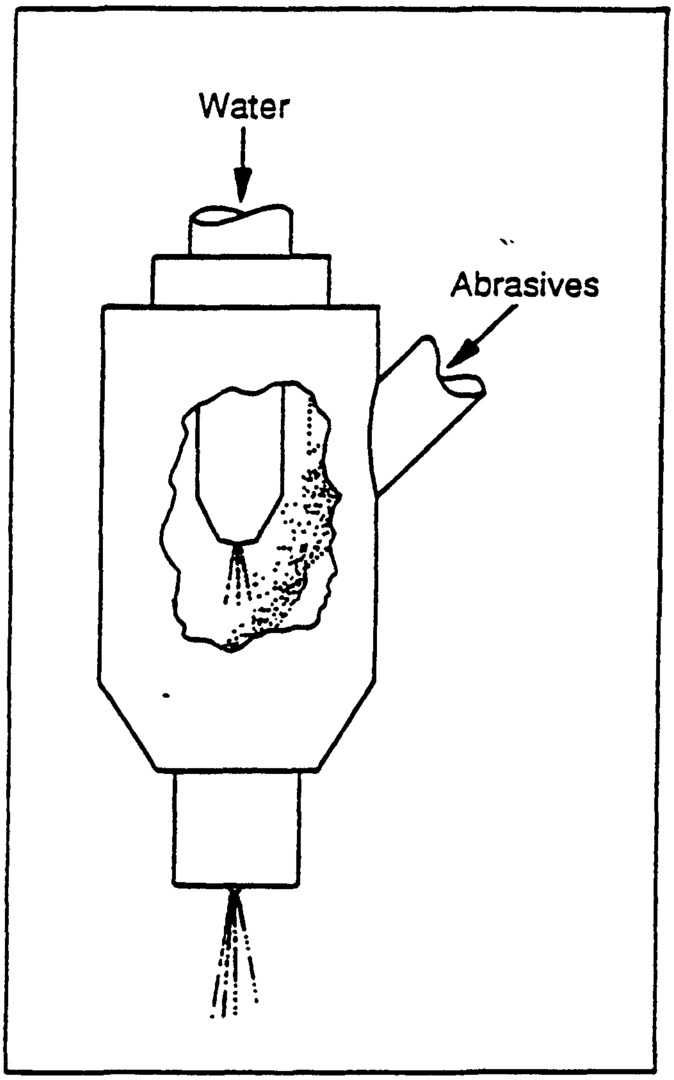

Figure 2-10. Hydraulic blasting nozzle.[13]

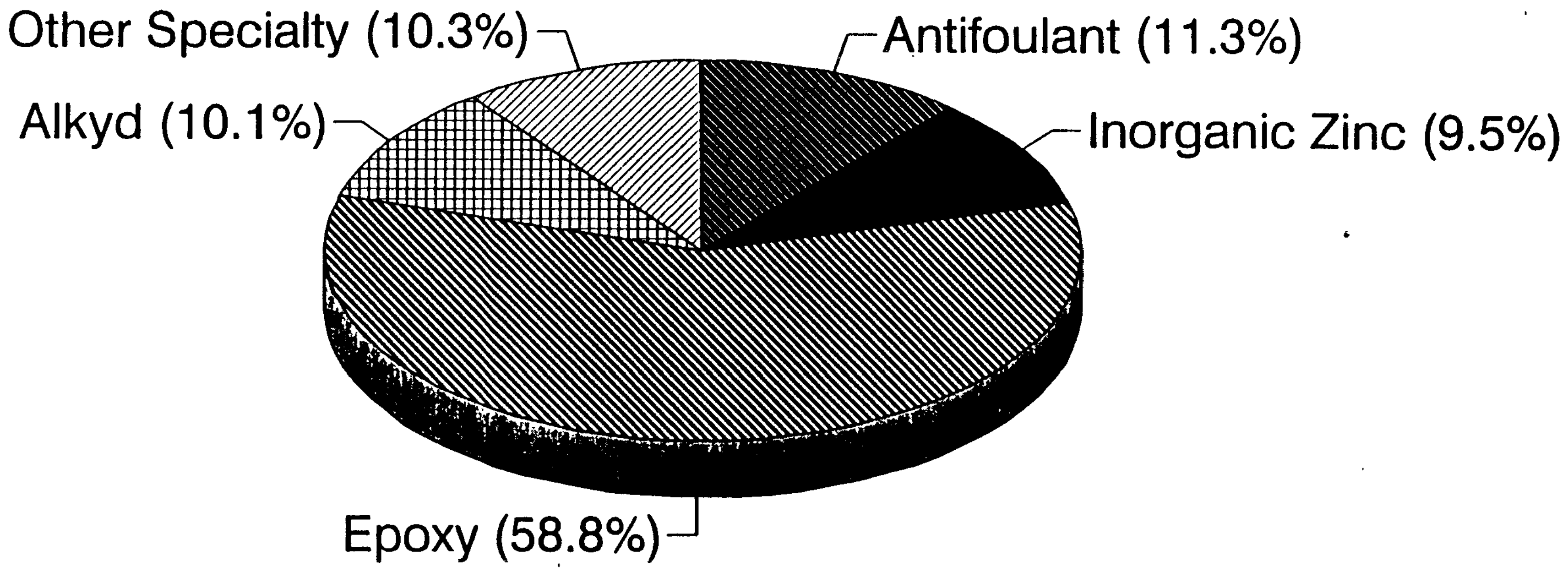

Figure 2-11. Paint category usage.[5]

TABLE 2-9. AVERAGE VOC CONTENT OF "AS SUPPLIED" PAINTS[5]

Paint category	Total reported usage, L (gal)[a]	Average VOC content	
		g/L (less water and "exempt" solvents)	lb/gal (less water and "exempt" solvents)
General use - Alkyd	604,765 (159,658)	474	3.95
General use - epoxy	3,515,080 (927,981)	350	2.92
Antifoulant	674,466 (178,059)	388	3.23
Repair and maintenance thermoplastics	122,886 (32,422)	493	4.11
Fire retardant	297,432 (78,522)	360	3.00
Heat resistant/high temperature (HR/HT)	22,360 (5,903)	466	3.88
High gloss	65,174 (17,206)	492	4.10
Inorganic zinc	570,064 (150,497)	545	4.54
Nuclear (low activation interior-LAI)	35,026 (9,247)	401	3.34
Organic zinc	28,114 (7,422)	548	4.57
Pretreatment wash primer	8,235 (2,174)	712	5.93
Special marking	38,473 (10,157)	446	3.72

[a] Total from the 37 shipyard responses in data base.[5]

values are the sums of the solvent contents of all reported paint and thinning solvents used. The figures do not include the contribution of reaction byproducts to the total VOC emitted. Paint/solvent usage breakdowns for each model yard are provided in Chapter 4, as are baseline emissions estimates for each of the uncontrolled model plant categories.

2.3.2 PM-10 Emissions

Table 2-10 summarizes the test data available on PM-10 and respirable particulate matter (RP) emissions from the abrasive blasting of ship hulls and other structures. The data sets were evaluated using the criteria and rating system developed by EPA's Office of Air Quality Planning and Standards (OAQPS) for developing AP-42 emission factors. In those cases where emission factors were presented in the reference document, the reliability of these emission factors was indicated by an overall rating ranging from A (excellent) to E (unacceptable). These ratings took into account the type and amount of data from which the factors were derived. Based on the criteria and rating system developed by OAQPS, emission factors reported in Table 2-10 for particulate matter emissions from abrasive blasting operations were below average in quality.[13] Although measurable levels of RP were documented from blasting ship hulls, there was insufficient information to support the relationship between the amount of PM-10 found, the type of abrasive, and the type of docking facility tested. Emissions data gathered for abrasive blasting of ship hulls and other structures (Table 2-10) are incomplete and give little insight. Therefore, it is concluded that the currently available data gathered for nonsimilar applications cannot be used to estimate emissions from blasting operations at shipyards.

If the analogy of spraying paint and blasting media against substrates has any validity, it is clear that developing emission factors for blasting will be challenging. Studies of paint spray transfer efficiency (the portion of paint leaving the spray gun that adheres to the substrate being painted) conducted by the U. S. EPA several years ago revealed that the variable to which

TABLE 2-10. SUMMARY OF TEST DATA FOR UNCONTROLLED ABRASIVE BLASTING OPERATIONS[13]

Reference document	Type of operation tested	Type of abrasive	Sampler location	Particle size fraction, μmA[a]	Time-weighted average concentration, mg/m^3	Data quality rating	Emission factor, mass/source extent	Emission factor rating	Comments
Samini et al., 1974	Abrasive cleaning of ship hull	Sand-blast	4.6 m (<5 yd) from source	TP	10.2	A	N/A[b]	N/A	Sampling time = 185 min
				RP	4.6	A	N/A	N/A	Blasting time = 180 min; no process data
			Sandblaster's chest	RP	88.8	A	N/A	N/A	Sampling time = 181 min Blasting time = 150 min; no process data
			9.1 m (<10 yd) from source	RP	2.36-9.08	A	N/A	N/A	No process data available
Landrigan et al., 1980	Abrasive bridge cleaning of lead-based paint	Grit (Black Beauty)	27 m downwind of bridge	TSP (Pb)	0.0129	B	N/A	N/A	Data for a 6.1-hr sampling period during which canvas shroud was not in place for a 2-hr period; Pb contributions from paint chips, vehicle exhaust, and grit; no process data available
Bareford and Record, 1982	Abrasive bridge cleaning of lead-based paint	Sand	Center of plume exiting sandblasting bay	TP	N/A	N/A	57-455 lb/hr/ abrasive blaster	D	2.5% Pb for particles <2.4 μm; sand usage 700 lb/hr/blaster (no exact throughput available)
				TP (Pb)	N/A	N/A	1.5-4.8 lb/hr/ abrasive blaster	D	<1% Pb for particles >75 μm; sand usage 700 lb/hr/blaster (no exact throughput available)
		Sand	Center of plume exiting sandblasting bay	<10	N/A	N/A	24 lb/hr/abrasive blaster	D	Sand usage 700 lb/hr/blaster (no exact throughput available)
				<10 (Pb)	N/A	N/A	0.46 lb/hr/ abrasive blaster	D	Sand usage 700 lb/hr/blaster (no exact throughput available)
Department of Navy, 1973	Abrasive blasting of submarine hull in drydock	Green Diamond slag	50 ft from source	TP 1 to 6.5 million particles per ft^3	N/A	N/A	N/A	N/A	
		Green Diamond slag	In vicinity of sand loader	TP 165 million particles per ft^3	N/A	N/A	N/A	N/A	

[a] TP = Total particulate matter.
RP = Respirable particulate matter ($\leq$3.5 μmA) as determined using a 10-mm nylon cyclone followed by a 37-mm filter cassette.
TSP = Total suspended particulate ($\leq$30-50 μmA) as determined by a high-volume air sampler.
[b] N/A = Not available or not applicable.

transfer efficiency is most sensitive is the velocity of ventilation air in the spray booth.

One could readily conclude that the emissions of fine particulate associated with blasting are a function of the particle distribution of the blast media, the friability of both the media and the coating and corrosion products being removed, wind speed and direction, relative humidity, and downwind distance of the sampling point. If true, the accuracy or validity of emission factors will continue to be gross estimates until a study is performed that incorporate all of the essential variables.

It is believed that any PM-10 released by the blasting process is likely to be found among the more visible portion of the downwind plume and would likely remain airborne longer than the larger (heavier) particulate. Using such reasoning, one could conclude that any visible downwind plume contains some PM-10, and the further from the blast site, the greater its portion of the total particulate, as it is naturally winnowed from the larger particles.

2.4 EXISTING REGULATIONS

Regulations that affect the emissions of VOC's and PM-10 from shipyards are discussed in this section. First, the constraints imposed upon shipyards by the Clean Air Act Amendments of 1990 are discussed. This discussion is followed by a summary of existing regulations for VOC and PM-10 emissions that are used in various States to control emissions from shipyards.

2.4.1 Requirements of the Clean Air Act Amendments of 1990

Section 130 of the 1990 Amendments requires EPA within 6 months after enactment, and at least every 3 years thereafter, to review and, if necessary, revise methods for estimating emissions. These emission estimation methods are used primarily by States to develop emission inventories for criteria pollutants in nonattainment areas (NAA's) (areas not meeting the National Ambient Air Quality Standards [NAAQS]). The criteria pollutant emission inventories are used to develop control strategies that are reflected in State implementation plans (SIP's), to track reasonable further progress for bringing NAA's into attainment with the NAAQS, and to perform air quality studies and monitoring. Shipyards are one of the sources that need to be considered in the SIP process.

2.4.1.1 Area Classifications. Nonattainment areas are designated by EPA, which assigns one of five classes for ozone and one of two classes for PM-10. Table 2-11 shows the criteria by which EPA designates the nonattainment classes and the respective dates by which the 1990 Amendments require that attainment of the NAAQS for ozone and PM-10 must be met. For the purpose of class designation, the ozone design value for an area is defined as the facility's fourth highest monitored ozone concentration for the years 1987 through 1989.

2.4.1.2 Ozone and PM-10 Emission Inventories. The 1990 Amendments require States with ozone NAA's in any of the five area classes shown in Table 2-11 to have submitted a baseline emission inventory for those areas by November 15, 1992. This baseline emission inventory must be based on the 1990 peak ozone season, typically between June and August. Shipyards were to be one of the sources inventoried. All future progress toward attainment of the primary standard will be measured against the baseline emission inventories. The 1990 Amendments require States to submit periodic (revised) ozone emission inventories every 3 years, beginning November 15, 1995, until areas are in attainment with the primary standard. Figure 2-12 shows a timeline for State submittals of ozone emission inventories to EPA. The 1990 Amendments do not specifically require baseline emission inventories for PM-10 but do specify a schedule for PM-10 SIP submittals, which will probably require PM-10 emission inventories. The EPA plans for States with NAA's to submit PM-10 emission inventories according to the schedule shown in Figure 2-12.

It is anticipated that shipyard contributions to the reasonable further progress deadlines for ozone can be estimated and tracked using paint and solvent usage records. Emissions of

TABLE 2-11. 1990 CLEAN AIR ACT AMENDMENT ATTAINMENT DATES FOR PRIMARY STANDARD

Ozone			PM-10	
Area class	Design value, ppm	Attainment	Area class	Attainment
Marginal	0.121 up to (but not including) 0.138	November 15, 1993	Moderate	December 31, 1994 for Section 107(d)(4) areas, otherwise 6 years after designation
Moderate	0.138 up to (but not including) 0.160	November 15, 1996		
Serious	0.160 up to (but not including) 0.180	November 15, 1999	Serious	December 31, 2001 for Section 107(d)(4) areas, otherwise 10 years after designation
Severe	0.180 up to (but not including) 0.280	November 15, 2005		
Severe	0.180 up to (but not including) 0.190	November 15, 2005		
	0.190 up to (but not including) 0.280[a]	November 15, 2007		
Extreme	0.280 and above	November 15, 2010		

[a] 1988 ozone design value only.

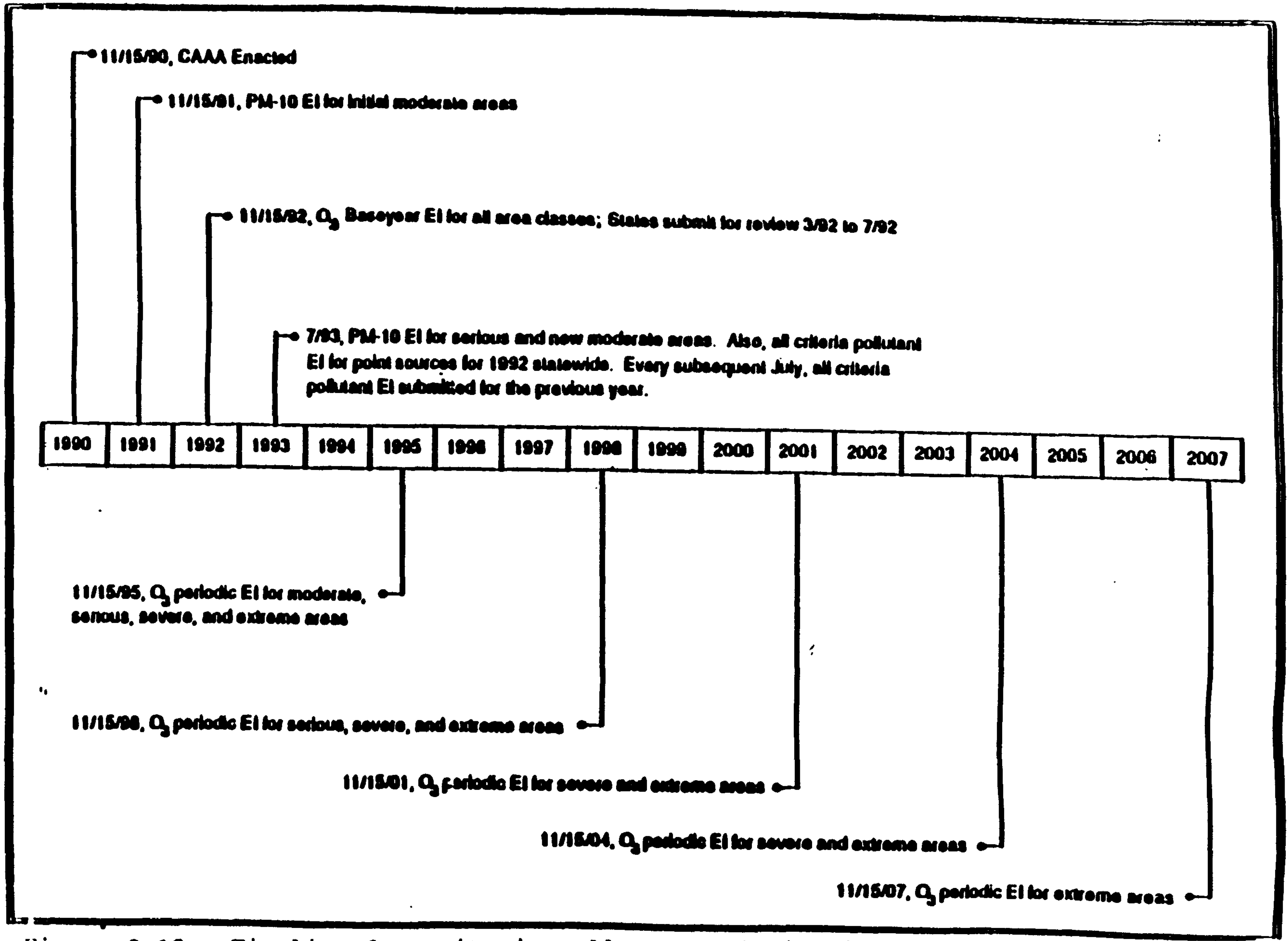

Figure 2-12. Timeline for criteria pollutant emission inventory State submittals.

PM-10, however, are unknown. Emission factors for PM-10 from shipyard operations have not yet been and will not be easily developed. For this reason, it will be difficult to estimate any potential contribution or reasonable further progress of the shipyard for PM-10.

2.4.2 Summary of Existing Regulations

An understanding of existing regulations is crucial in assessing regulatory and cost impacts, as well in determining appropriate control measures for the industry. States and localities with existing regulations are Virginia, Connecticut, Louisiana, Maine, Washington, Wisconsin, California, and California's Bay Area, South Coast, and San Diego County Air Pollution Control Districts.[11] Table 2-12 summarizes these regulations. The regulations pertain to the marine coating of ships and the resulting VOC emissions and to the outdoor abrasive blasting of ships and the associated PM-10 emissions. These regulations were reviewed to determine whether the rules are shipyard-specific. California and Louisiana are the only States with regulations that specifically address the shipbuilding and ship repair industry. For those States/localities and/or unit operations for which shipyard-specific regulations do not exist, there are general provisions for regulating emissions from shipyards. The regulations are described in greater detail below.

2.4.2.1 Marine Coating and VOC Requirements. The California Air Resources Board's and California's Bay Area, South Coast, and San Diego County Air Pollution Control Districts' regulations specifically limit emissions from the shipbuilding and ship repair industry. They specify maximum VOC contents for paints typically used in specific applications (e.g., as antifoulants). Louisiana enforces VOC limits for its shipyards by estimating facility emissions from paint material safety data sheets (MSDS's) and comparing those emissions with the maximum allowable VOC contents defined by the regulation. Louisiana has adopted VOC limits for various specialty marine coating categories that are similar to those adopted by California. (Use

TABLE 2-12. SUMMARY OF EXISTING REGULATIONS[11]

Area	Marine coatings and VOC's	Abrasive blasting and PM-10
California Air Resources Board (CARB)	Require use of low-VOC coatings. Require control of solvent emissions from equipment cleaning and thinning paint. See Table 2-14.	Stringent regulation. See Figure 2-13.
SCAQMD	Adopted CARB rules.	Adopted CARB rules.
BAAQMD	Adopted CARB rules.	Adopted CARB rules.
San Diego APCD	Adopted CARB rules.	Adopted CARB rules.
Connecticut	California's Rule 66. Generic RACT[a] for sources >100 tons. Require low-VOC paints for indoor coating.	N/A
Maine	Require new sources to use BACT[b]. Existing permitted sources renew operating licenses every 5 years.	N/A
Washington	Regulate spray coatings under general provisions.	Tarp blasting operations. Regulate on a "complaint basis." No blasting if wind speed is >20 mph.
Wisconsin	California's Rule 66.	Fugitive rule for particulate matter. Specific to blasting process.
Louisiana	Title 33 regulates criteria pollutants. Chapter 21 regulates VOC emissions reported on MSDS's. VOC limits similar to California's.	Require tarping of blasting area.
Virginia	N/A	20 percent opacity visibility standard. Require "adequate containment of sandblasting or similar operations."

N/A = Not available or not applicable.

[a] Reasonably available control technology.

[b] Best available control technology.

of the MSDS for compliance indicates that the enforcement mechanism incorporates a margin of safety for the shipyards. The EPA reference method considers cure volatiles which the MSDS does not.) A comparison of California and Louisiana VOC limits is given in Table 2-13.

Connecticut and Wisconsin do not regulate VOC emissions directly from shipyards. They do, however, require coating manufacturers to substitute slower reactive solvents using the old "California Rule 66" to delay formation of ozone. Rule 66, promulgated in California in 1962, required an 85 percent reduction in highly photochemically reactive compounds by substitution of more slowly reacting solvents that it identified as "exempt." In 1976, EPA published a VOC policy statement in the Federal Register that noted that essentially all organics are photochemically reactive and urged States to change their substitution rules as EPA provided more specific guidance. A few States have not withdrawn Rule 66 even though it does not constrain ozone formation.

Maine and Washington have general State provisions that allow VOC emissions to be regulated. Under Maine's regulations, new sources are required to use best available control technology (BACT) to control emissions, and existing permitted sources are required to renew their operating licenses every 5 years. Washington's Puget Sound Air Pollution Control Agency's rule restricts or prevents painting operations when wind speeds exceed 20 miles per hour (mph).

2.4.2.2 Abrasive Blasting and PM-10 Requirements. The most stringent abrasive blasting regulation adopted in the United States to date (adopted November 1990) is in the State of California. A summary of the regulation guidelines is provided in Figure 2-13.[18,19] The regulation states that abrasive blasting can be conducted either inside or outside of a permanent building. Stack emissions from indoor abrasive blasting must meet a Ringlemann 1 (20 percent opacity) visibility emission standard, regardless of the abrasive or the abrasive blasting method used. All outdoor abrasive blasting is required to meet a

TABLE 2-13. STATE VOC LIMIT COMPARISON[11]
(Expressed in units of g/L and lb/gal of coating as applied, minus water and exempt solvent)

	California VOC limits				Louisiana VOC limits	
	g/L		lb/gal		g/L	lb/gal
Coating category	Sept. '92	Sept. '94	Sept. '92	Sept. '94	July '91	
General limits	340	340	2.8	2.8	420	3.5
Antenna	530	340	4.4	2.8	490	4.1
Antifoulant	400	400	3.3	3.3	440	3.7
Heat-resistant	420	420	3.5	3.5	420	3.5
High-gloss	420	420	3.5	3.5	420	3.5
High-temperature	500	500	4.2	4.2	650	5.4
Inorganic zinc	650	340	5.4	2.8	650	5.4
Low-activation interior (Nuclear)	420	420	3.5	3.5	490	4.1
Military exterior	340	340	2.8	2.8	420	3.5
Navigational aids	550	340	4.6	2.8	420	3.5
Pretreatment wash primer	780	420	6.5	3.5	780	6.5
Repair and maintenance thermoplastics	550	340	4.6	2.8	650	5.4
Wire spray sealant	610	610	5.1	5.1	648	5.4
Specialty interior	340	340	2.8	2.8	420	3.5
Special marking	490	420	4.1	3.5	490	4.1
Tack coat	610	610	5.1	5.1	610	5.1
Undersea weapons systems	340	340	2.8	2.8	–	–
Extreme high-gloss	N/A	N/A	N/A	N/A	490	4.1
Metallic heat-resistant	N/A	N/A	N/A	N/A	530	4.4
Anchor chain asphalt (TT-V-51)	N/A	N/A	N/A	N/A	620	5.2
Wood spar varnish (TT-V-119)	N/A	N/A	N/A	N/A	492	4.1
Dull black finish (DOD-P-15146)	N/A	N/A	N/A	N/A	444	3.7
Tank coatings (DOD-P-23236)	N/A	N/A	N/A	N/A	420	3.5
Potable water tank coating (DOD-P-23236)	N/A	N/A	N/A	N/A	444	3.7
Flight deck markings (DOD-C-24667)	N/A	N/A	N/A	N/A	504	4.2
Vinyl acrylic top coats	N/A	N/A	N/A	N/A	648	5.4
Antifoulants on aluminum hulls	N/A	N/A	N/A	N/A	550	4.5
Elastomeric adhesives (with 15 wt % rubber)	N/A	N/A	N/A	N/A	730	6.1

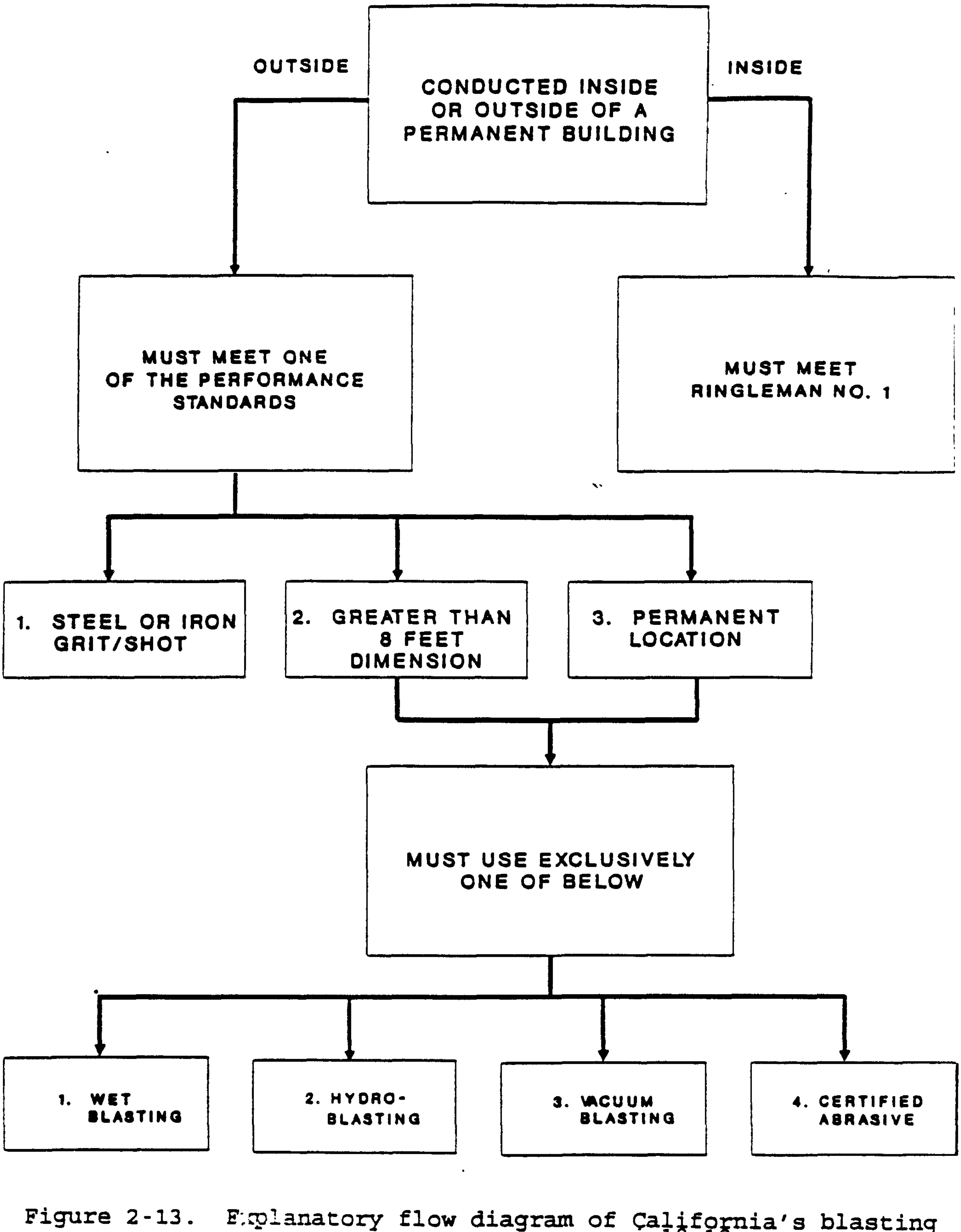

Figure 2-13. Explanatory flow diagram of California's blasting regulation provided by NASSCO.[18,19]

Ringlemann 2 (40 percent opacity) visibility emission standard. To conduct abrasive blasting outside, one of these criteria must be met: (1) steel or iron shot/grit must be used exclusively, (2) the item being blasted must exceed 8 ft in any dimension, or (3) the item being blasted must be at or close to its permanent location. If Options 2 and 3 are met, then wet abrasive blasting, hydroblasting, vacuum blasting, or dry blasting with a certified abrasive must be used. The grades and brands of abrasives certified by CARB are listed in Table 2-14. According to the regulation, abrasives are certified biannually based on particle size and distribution. Abrasives are certified to restrict the types of abrasives used in dry unconfined blasting for the purpose of reducing the amount of fine particles introduced to the blasting process. The particle size and distribution constraints ("cut-point for fineness") criterion allows abrasives to be reused only if they can be shown to still meet the physical requirements.[18]

Virginia, Washington, and Wisconsin also have requirements for open blasting operations. These regulate total particulates, not PM-10. Virginia has adopted a general 20 percent opacity visibility emission standard. Virginia has also adopted a standard that requires facilities to take reasonable precautions to prevent particulate matter from becoming airborne. Washington's Puget Sound rules state that if fugitive dust from blasting (or any process) becomes a public nuisance, the agency can intervene with some measure to reduce the fugitive emissions. The agency also restricts blasting operations when wind speeds exceed 20 mph. Wisconsin has adopted a general fugitive rule for PM emissions from blasting.[13]

TABLE 2-14. ABRASIVES CERTIFIED BY CARB

Company	Brand name or grade
Alpheus Cleaning Technologies Corp. Rancho Cucamonga, CA	CO_2 Cleanblast
Apache Abrasive, Inc. Houston, TX	Apache-Blast 12-50 and Utility
Applied Industrial Materials Corp., (AIMCOR) Deerfield, IL	Green Lightning 20 x 46
R.A. Barnes, Inc. Portland, OR	Safe-T-Blast Types I and II
Barton Mines Corp. North Creek, NY	Barton 1640
Blackhawk Slag Products Midvale, CT	Blackhawk; Fine, Medium, Utility
California Silica Products Company San Juan Capistrano, CA	Nos. 12, 16, 20, 30
Cominco-American Resources, Glenbrook Nickel Company Riddle, OR	Ruby Garnet; 16, 36
Corona Industrial Sand Company Corona, CA	Cisco Nos. 12, 16, 20, 30
Crystal Peak Garnet Corp. Vancouver, BC, Canada	16-40
Desert Garnet Cadix, CA	Gemshot Nos. 36, 30-60 Geronimo Nos. 36, 30-60
Don Kelland Materials, Inc. Yuma, AZ	Arizona Utility
Dwyer Consolidated Mines, Inc. Thousand Palms, CA	Garnet Storm Nos. 16, 20, 40, 60
E. I. Du Pont de Nemours & Company, Inc. Wilmington, DE	Starblast, cpff = No. 200 sieve Starblast XL, cpff = No. 200 sieve Zirclean, cpff = 270 sieve
Emerald Creek Garnet Milling Company Fernwood, ID Gordon Sand Company Compton, CA	Nos. 36, 30/40, 50X
Foster-Dixiana Corp. Columbia, SC Norfolk Plant Chesapeake, VA Columbia Plant West Columbia, SC Savannah Plant Hardeeville, SC	Black Diamond-CX8, CX12
Fusco Abrasive Systems, Inc. Compton, CA	U.S. Technology Corp., Poly Plus

TABLE 2-14. (continued)

Company	Brand name or grade
Garnet Millers Australia (manufacturer) Geraldton, Australia Barton Mines Corp. Golden, CO Gordan Sand Company (distributor) Compton, GA	ROM 30 X 60
Gemstar Stone Products Company Hunt Valley, MD	Camel Black, Utility Grade
P. W. Gillibrand Company Simi Valley, CA	Gillibrand; Silver Nos. 12, 16, 20, 30 Gillibrand; M-16, M-20, M-30
Glenbrook Nickel Company Riddle, OR	Green Diamond; 10-40, 16-36, 16-50, 20-50
Gordan Sand Company Compton, CA	Golden Flint; G-16, G-20, G30 Lapis Luster; G-12 Silver Flint; S-12, S-16, S-20, S-30
Grangrit, Inc. Harvey, LA	Grangrit-Medium
Harsco Corp., Reed Mineral Division Highland, IN Reed Minerals/Harsco Memphis, TN Concord [Bowl], NH Gary, NH Drakesboro, KY	Black Beauty-2250 Black Beauty-1243, 2043 Black Beauty-2550 Black Beauty-1040, Black Beauty-1240
Hydro-Air Products, Inc. Vernon, CA	Du Pont Coarse Staurolite
Industrial Minerals Products Inc., reserve abrasives Cebu City, Phillipines	Utility
Kayway Industries, Inc. Winnipeg, Mantoba, Canada	Kayway Grit; 16-30, 20-40
3M Company Corona, CA	3M; C-110, C-111
Minerals Research and Recovery of Arizona, Inc. Tuscon, AZ	Sharpshot; F-80(25), F-80(36), M-60
Pacific Abrasives & Supply & Inc. Grand Forks, BC, Canada	Kleen Blast; 16-30, 35, 16, 8-12, 30-60
Parker Brothers & Company, Inc. Houston, TX	8-20, 12-50
Parker Mining Corp. San Francisco, CA	Little Sister Garnet Grade; 28, 40

TABLE 2-14. (continued)

Company	Brand name or grade
RDM Multi-Enterprises, Inc. Anaconda, MT	Ferro Blast; 8-20, 16-30, 36 fine, 30-60 X-fine Best Grith; 8-20, 16-30, 36 fine, 30-60 X-fine Ferro Blast-73 Nos. 8/20, 16/30, 36
Ron Hanna Mining Company Prescott, AZ	Superior; coarse, medium
RMC Lonestar Pleasanton, CA	Lapis-Luster Nos. 3, 1/20, 1C, 2/12, 2/16, 0/30 Clementina Nos. 3, 1/20, 1C, 2/12, 2/16, 0/30
Spreckles Limestone and Aggregate Products Cool, GA	Calcarb; medium, coarse
Silica Resources, Inc. Marysville, CA	SRI Premium Nos. 8, 12, 16, 20, 30
Stan-Blast Abrasive Company, Inc. Harvey, LA	Stan-Blast-Galveston, TX San-Blast-Harvey, LA
Tidewater Materials of Virginia, Inc. Houston, TX	Sure-Shot Utility (New Orleans plant) Sure-Shot Utility (Portsmouth plant)
Unimim Corp. Emmett, ID	Granusil Nos. 16, 20, 30
Union Pacific Resources Magna, UT	Copper Blast Medium Dynacut; 100, coarse, medium MSR (fine)
Valley Sand and Gravel Trona, CA	Desert Diamond coarse, medium
Virginia Materials Corp. Norfolk, VA	VMC Black Blast
Waupaca Materials, a division of Falks Bros. Construction Company, Inc. Waupaca, WI	Blackjack MSM

[a]cpff = cut point for fineness.

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3.0 EMISSION CONTROL TECHNIQUES

3.1 INTRODUCTION

Emissions from shipyard operations are primarily volatile organic compound (VOC) emissions that result from shipyard painting operations. Particulate matter less than 10 microns in diameter (PM-10) also is emitted from abrasive blasting conducted to prepare ship surfaces for painting. This chapter discusses control techniques that are demonstrated and those for which technology transfer appears to be applicable to control shipyard emissions. Section 3.2 discusses the control techniques that apply to painting, Section 3.3 discusses those that apply to cleaning, and controls that can be applied to abrasive blasting operations are discussed in Section 3.4. In addition, Section 3.5 discusses other available measures for both VOC and PM-10 emissions control.

3.2 PAINTING OPERATIONS

Emissions of VOC's from painting operations result from three components: (1) organic solvent in the paint "as supplied" by the paint manufacturer, (2) organic solvent in the thinner, which is added to the paint prior to application and becomes part of the paint "as applied", and (3) any additional volatile organic released during the cure. The organic solvents from both components are emitted as the applied paint dries/cures. This organic solvent portion of a paint is composed of a mixture of different solvents that perform either of two equally important functions: (1) reduce viscosity so the paint can be atomized as it leaves the spray gun or (2) provide essential surface characteristics of the paint once it is applied. Solvents used for atomization typically have low boiling points and flash to a vapor upon leaving the spray gun. These solvents evaporate relatively quickly during initial drying to prevent excessive flow. Solvents responsible for imparting the desired surface characteristics must have higher boiling points and subsequently evaporate more slowly than atomizing solvents to allow sufficient leveling and adhesion.[1] Of the solvents used in marine paints, most are VOC's.[2]

3.2.1 Lower-VOC Coatings

Historically, the selection of marine paints was centered around two characteristics, performance, and cost. Now, with the implementation of the 1990 Clean Air Act Amendments, the emphasis will shift to lowering both the VOC and hazardous air pollution (HAP) content of paints. Since most HAPs that are found in paint are volatile organics, the previous trend to lower VOC coatings has undoubtedly also reduced HAPs in the aggregate! Lower VOC coatings have been of two general types, waterborne and higher-solids coatings. Both have a lower VOC-to-solids ratio than traditional coatings.[3] Waterbornes have not made significant inroads into this industry. The regulatory alternatives presented are all essentially based on higher solids formulations.

3.2.2 Paint Heating Systems

Paint heaters can be used in place of or in conjunction with paint solvents (i.e., thinners, reducers, etc.) to reduce paint viscosity by heating the paint prior to application using an in-line heating element just upstream of the spray gun. Paint heaters are used by at least two shipyards and many have also been used in a variety of industrial and automotive paint applications.[2] These heaters appear adaptable to any paint spray system but are most often used to reduce the viscosity of higher-solids coatings. The increase in paint temperature that a single heater can provide depends on the paint flow rate; the lower the flowrate, the greater the temperature increase. One manufacturer indicates that an in-line heater can increase paint temperatures by 38°C (100°F) at 0.76 liters per minute (L/min) (0.2 gallon per minute [gal/min]), 22°C (72°F) at 1.51 L/min (0.4 gal/min), and 6°C (43°F) at 3.0 L/min (0.8 gal/min).[4] The relationship between temperature and viscosity varies somewhat between coatings and depends on the physical properties of the paint.

Paint heaters reportedly are not a panacea for visosity problems. Representatives of shipyards in colder climates have complained that applying heated paint to cold surfaces in winter months results in poor paint surface characteristics (i.e., cracking) because of the rapid cooling of the hot paint after it is applied to the cold surface.[2]

3.2.3 VOC Add-On Controls

Add-on pollution control devices are used by many industries to control VOC emissions from paints. The efficiency of the control system depends on the capture efficiency of the enclosure used to contain the paint emissions as well as the removal/destruction efficiency of the add-on control device to which the emissions are routed.

Most of the painting that occurs within this industry involves outdoor painting of very large vessels. Emissions from outdoor painting are expensive to control due to the difficulty of effectively enclosing the large substrates. With existing technology, add-on controls are technically feasible for only one outdoor painting process, the painting of tanks, because the tank itself is a natural enclosure. See Chapter 5 and Appendix C for cost information.

One recent innovation, a patented portable enclosure system to contain grit during hull blasting, has potential for containing VOC as well. Pilot demonstrations have been conducted, but the device is not yet commercially available.

A small percentage of indoor painting is performed relative to outdoor painting: This includes painting of internal ship compartments and spray booth painting of smaller ship parts within buildings prior to assembly. Because emissions from indoor painting operations are more esily contained, it is technically feasible to capture and route emissions directly to a control device.

For control of indoor painting (including tanks) emissions, the add-on devices evaluated are thermal and catalytic incinerators and carbon adsorption systems. Incinerators are control devices that destroy VOC contaminants using combustion, converting them primarily to carbon dioxide (CO_2) and water. Carbon adsorbers are recovery devices that collect VOC's on an activated carbon bed. The VOC's are recovered when the carbon bed is regenerated using steam or hot air. The steam or hot air also reactivates the carbon bed. The recovered VOC's are then disposed of or destroyed. Summaries of these add-on control devices, their associated costs, and their performance characteristics are in References 6, 7, and 8, respectively.

3.2.4 Potential Emission Reductions

Chapter 2 identifies the coating categories used for specialty purposes in the marine industry. All other paints that are not used for these specialty purposes are considered a "general-use" paint. General-use paints are identified by resin type, e.g. epoxies and alkyds. Of the 23 categories (22 specialty and 1 general-use), 3 account for approximately 90 percent of the total emissions: antifoulants, inorganic zincs, and general-use (primarily the: epoxies and alkyds). Emission reductions options were evaluated for these three coating categories.

California limits for these three categories were developed in the late 1980's to force research for lower VOC coatings. Those limits, now being achieved by shipyards in that state, were used as a benchmark. Emission reductions elsewhere across the Nation were estimated by calculating the emission reductions achievable if coatings currently in use were replaced with higher solids products. It was assumed that those yards currently using higher VOC coatings would switch to coatings with VOC levels equal to the weighted average VOC content of all coatings in the data base at or below a regulatory limit. In other words, it was assumed that the distribution of all higher solids coatings used after a role is in effect would be similar to that of the compliant coatings currently available.

Also, the emission reductions that could be achieved by using paint heaters in lieu of or in conjunction with thinning solvents were evaluated as was the reductions associated with ducting spray booth emissions to add-on control devices. Reductions in VOC emissions would be obtained from all of these control options; however, by far the most significant reductions would result from shipyards transitioning to reformulated coatings. The reductions achieved from implementing these options and the associated costs are outlined in more detail in Chapter 5.

3.3 SOLVENT CLEANING

The Alternative Control Techniques (ACT) document for Industrial Cleaning Solvents [9] suggests a two-step program for reducing solvent emissions. The first element of this program consists of tracking the use, fate, and costs of all cleaning solvents. The second element consists of actions management may take to reduce or control emissions based on the knowledge of gained cleaning solvent use, fate, and costs. [9]

Cleaning solvents are used at shipyards to prepare surfaces prior to painting and to clean spray equipment including spray guns, lines, pumps, and containers (pots) used to hold the paint. All of the equipment, except the pots, are usually cleaned by purging solvent through the spray system (i.e., the spray gun with the paint line and pump still attached) into a container. The solvent-filled container is then emptied into a 55-gallon waste drum. Paint pots are also cleaned with solvent. Any dried paint remaining in the pot after cleaning is removed with a brush.[2,10] The ACT discusses cleaning practices and work practices for reducing evaporation during use thereby reducing solvent purchase and disposal costs. It also encourages investigation of alternative cleaning solutions including substitution of solvents that are less volatile.

3.3.1 Cleaning Practice Modifications [9]

Certain cleaning practices can be modified to minimize the amount of solvent used as well as the evaporative losses. Using special solvent dispensers for wiping a surface with rags and disposing of the rags in a covered container will help reduce evaporation. Also, emptying the spray gun of paint prior to cleaning (i.e., spraying the equipment dry) and cleaning equipment promptly after use (not allowing the paint to dry in/on equipment) reduce the amount of solvent required.

Cleaning practices that reduce evaporative emissions include (1) lowering the gun pressure (decreasing air and paint pressure) during cleaning to eliminate or minimize atomization of the solvent, and (2) storing solvent in closed containers and discharging cleaning solvent into a vented container through a small opening that accommodate only the tip of the spray gun.

Waste solvent containers release solvent vapor each time one is opened due both to displacement when new solvent is added and the effect of air movement across the opening. When left uncovered, solvent will evaporate constantly. Emissions also occur when solvent is poured from one container into another.

A variety of devices have been developed that minimize evaporative emissions. An example is self-closing funnels. These screw into the bung hole on a container and minimize emissions because the barrel is normally closed, sealed when solvent is not being added. They also reduce spillage.

3.3.2 Substitute Solvents in Cleaning Materials

Several low-VOC cleaning products are available that may be used in place of solvents. The chemical behavior of these substitutes (i.e., vapor pressures, drying times, cleaning effectiveness, etc.) may differ from that of the solvent which it replaces. These behavioral differences may require changes in cleaning practices.

3.3.3 Potential Emission Reductions

Significant emission reductions can often be achieved by changes in cleaning practices and/or cleaning materials. This was verified by two companies whose case studies are presented in

Chapter 5 of the alternative control techniques document (ACT) for Industrial Cleaning Solvents.[9]

3.4 ABRASIVE BLASTING OPERATIONS

Emissions of PM-10 from abrasive blasting operations are a function of the blast media used, the paint and corrosion products being removed, and the wind and weather conditions in which the blasting occurs. Section 3.4.1 presents the mechanisms available to control or reduce PM-10 emissions, and Section 3.4.2 discusses why emissions of PM-10 cannot be estimated for this industry.

3.4.1 PM-10 Control Techniques

A number of technologies are used to contain debris generated from abrasive blasting and to reduce or control PM-10 emissions. Others are under development. The existing technologies consist of drydock covers (use of tarpaulins in a variety of ways to inhibit emissions), vacuum blasters, water curtains, wet blasters, centrifugal blasters, improved abrasives, and underwater cleaning. These control techniques are summarized in Table 3-1. The technologies under development include the SCHLICK blast cleaning systems being developed in Germany and a portable enclosure system being developed by Metro-Machine Shipyard in Virginia. [5,11]

3.4.1.1 Current Technologies.

3.4.1.1.1 Blast enclosures. Blast enclosures are designed to completely enclose one or more abrasive blast operators, thereby confining the blast debris.[12] The enclosure floor is usually equipped with funnels to divert the captured debris into adjacent trucks. In one design, a ventilation system removes the airborne dust from the enclosure by using a wet scrubber to remove the particles from the effluent airstream air. Alternatively, baghouses or other dust collectors can be used to control dust emissions.

Blast enclosures can be very effective in containing and recovering abrasive blast debris. However, they are specifically designed for a particular application (e.g. recovery of lead), are relatively expensive, and tend to slow down the overall

TABLE 3-1. SUMMARY OF ABRASIVE BLASTING CONTROL OPTIONS[12-18]

Control option	Advantages	Disadvantages
Blast enclosures	- Effective control - Work can continue under inclement weather conditions	- Must be specifically designed for a particular application - Expensive (permanent structures only)
Dry dock covers	- Offer some suppression of airborne particulates - Movable from one ship area to the next	- Flimsy and detach under high wind conditions - Crane access is limited for large ships
Vacuum blasters	- Good for small or touch-up jobs where neighboring surfaces should not be disturbed - Often used to touch up weld joints	- Heavy and awkward to use - Paint removal is very slow - Operator cannot see surface while blasting
Schlict vaccum blaster	- Faster than manual - Robotic motion	- Costly
Water curtains	- Relatively inexpensive (controversial)	- Generate wastewater and potential water pollution problems
Wet blasting	- Substantially lower dust emissions	- Debris more difficult to clean up - Generates wastewater problem - Without abrasive, water blasting is slow, surface is not adequately prepared, and corrosion problems occur
Improved abrasives	- Lower dust emissions due to fewer dust particles in media and fewer dust particles generated during blasting with "hard" abrasives	- Can be costly unless adequate means of recycling available
Water cleaning	- Reduces abrasive blast media usage rate if cleaning performed while hull is wet	- Does not remove paint

cleaning rate due to the time required to move the enclosure as the work progresses.

Some leakage of abrasive and paint debris can also occur at the joints between the blast enclosure and the structure being cleaned. Although attempts have been made to seal the joints with canvas, this is usually not very effective, particularly when the blast is directed into these areas. A better method to minimize leakage from enclosure joints is to fasten a flexible seal made of rubber, plastic, or thin metal to the inside edges of the enclosure walls. The end of the flexible seal rests on the structure being cleaned, thus reducing the escape of airborne dust.[13]

3.4.1.1.2 Drydock covers. Several schemes that use some form of drydock cover have been evaluated. "Cocooning" consists of draping plastic/fabric tarps from the drydock walls to the hulls and superstructures of ships. This form of drydock cover provides some suppression of airborne particulates; however, the tarps have a tendency to detach and tear under moderate to high wind conditions. Also, cocooning a ship limits the accessibility of drydock cranes to the covered ship. Another common measure for suppressing dust emissions is erecting a fabric barrier to close off the end of the drydock. Because they do not completely enclose the ship, these barriers would appear to be less effective than cocooning regardless of the cocoon's quality.[16]

Puget Sound Naval Shipyard completely roofs the drydock during abrasive blasting of submarines with reportedly complete containment of blast particulates. Because the vertical height of the submarine is less than the top of the drydock, roofing is simplified. However, for larger surface ships, the Navy believes that a complete cover may be an impractical approach. An alternative approach under consideration for development by the Navy is encapsulation by air-supported, bubble-like structures.[14]

3.4.1.1.3 Vacuum blasters. Vacuum blasters are designed to remove paint and other surface coatings by abrasive blasting and simultaneously collecting and recovering the spent abrasive and paint debris with a capture and collection system surrounding the blast nozzle (Figure 3-1).

In this type of system, the abrasive is automatically reclaimed and reused as work progresses. Vacuum blasters are made in a variety of sizes, but even the smaller units are comparatively heavy and awkward to use.[15] Boston Naval Shipyard has been using a vacuum unit capable of picking up abrasive grit, wet sand, or slurry.[14] The vacuum unit is equipped with a moisturizer to trap dust from dry debris after collection. Newport News Shipbuilding uses vacuum blasting only for small jobs (e.g., a vacuum blaster is used on seams to be welded.) This yard estimates the system to be one-third as fast as conventional blasting because the area being blasted is obstructed from view by the blasting apparatus, the blast nozzle is smaller, and the worker must move along the blast surface slowly enough for the vacuum to capture the spent media before the nozzle is moved along.[16]

3.4.1.1.4 Water curtains. In this technique, a water header with a series of nozzles is installed along the edges of the structure being blasted. The water spray from the nozzles is directed downward, creating a water curtain to collect debris from abrasive blasting performed below the header, which is subsequently washed down to the ground. This technique is relatively inexpensive and does reduce the amount of airborne dust. It requires proper water containment and treatment facilities to avoid water contamination or other clean-up problems.[12] Multimedia transfer from air pollution to water pollution can cause an increase in hazardous waste stream and result in increasing operational cost.

One method used to avoid the spillage problem associated with water curtains involves placing troughs under the spray pattern to catch the water/abrasive mixture and divert it to an appropriate container (e.g., tank truck) for disposal. For low structures, the troughs can be placed on the ground. For high structures, the troughs can be supported from the structure itself.[12]

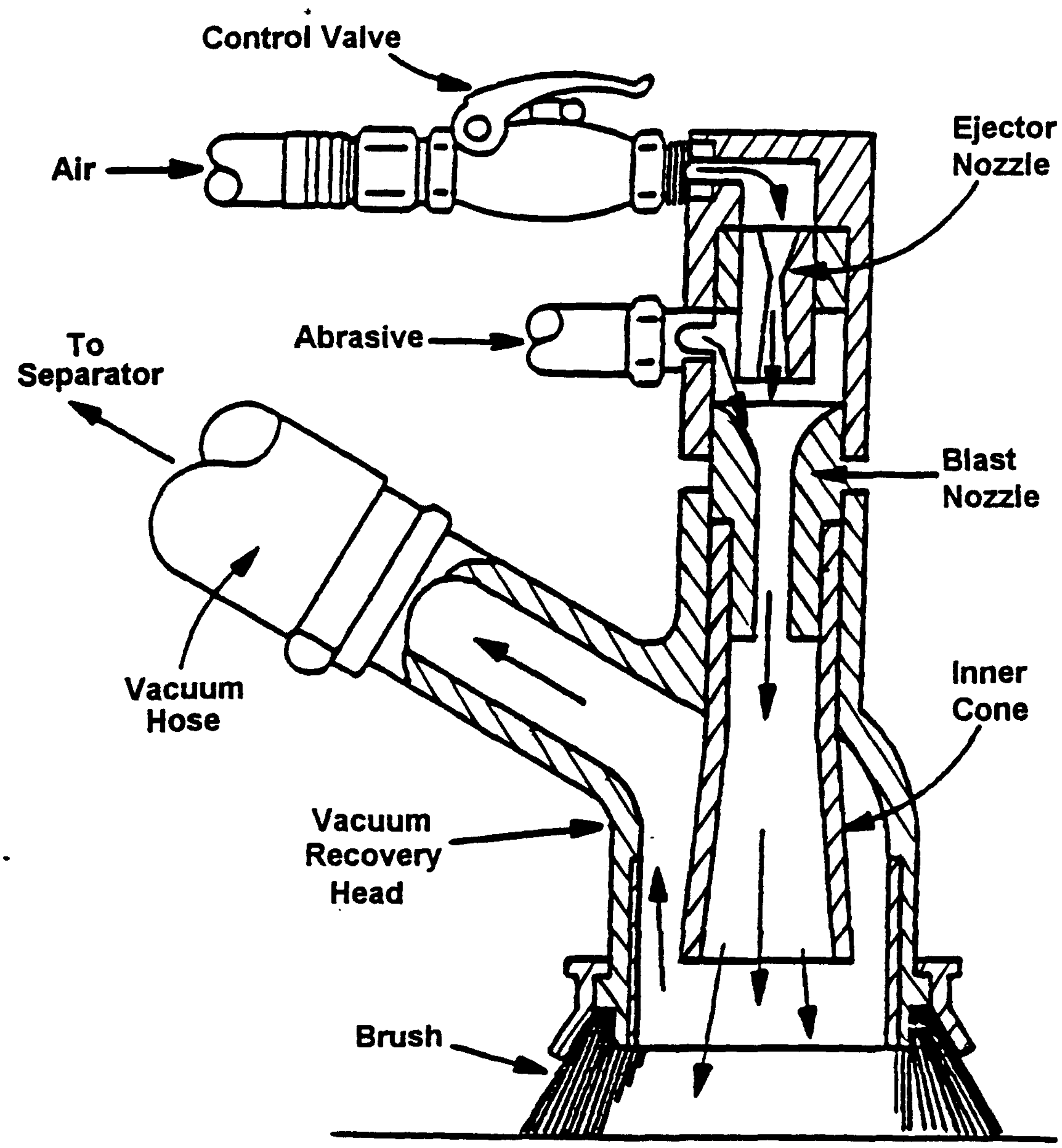

Figure 3-1. Schematic of vacuum blaster head.[15]

3.4.1.1.5 Wet blasting. Wet blasting techniques include wet abrasive blasting and high-pressure water blasting.[17] The type of wet blasting method used depends on the application.

Wet abrasive blasting was introduced in Chapter 2. Wet abrasive blasting is accomplished by adding water to conventional abrasive blasting nozzles. Most wet abrasive blasters mix the water with the abrasive prior to its impact on the surface. This interaction can cause the rate of surface cleaning to be slower than with dry abrasive blasting.[12] Other disadvantages include the need for touch-up abrasive steps and the need to include rust inhibitors and in some cases antifreeze solutions in the slurry. Such additives are water pollutants.

A retrofit device designed to minimize premixing of the water with the abrasive blast has been developed to fit over the end of conventional abrasive blast nozzles. This device is expected to be an improvement over traditional wet abrasive blasting, and is shown in Figure 3-2.[12] The two principal parts of the device are a swirl chamber and an exit nozzle. The swirl chamber is equipped with a tangential water inlet. The incoming water swirls around the inside of the chamber and then out the exit nozzle. Centrifugal force causes the water to form a hollow cone pattern around the abrasive blast stream. The angle of the water cone is controlled principally by the shape of the exit nozzle and centrifugal forces. The modified water nozzle design provides a water curtain around the abrasive/airstream. Thus, the cleaning effectiveness of the abrasive/airstream should not be substantially affected. The device is simple to install and operate with conventional abrasive blasting equipment.[12]

Long Beach Naval Shipyard studies show that enveloping the abrasive blast streams with a cone of water reduced the particulate generation by about 80 percent. However, this method can make removing the saturated abrasive from the drydock floor more difficult.[14]

High-pressure water blast systems include an engine-driven, high-pressure pump, a high-pressure hose, and a gun equipped with a spray nozzle. High-pressure water blasting using a pressurized

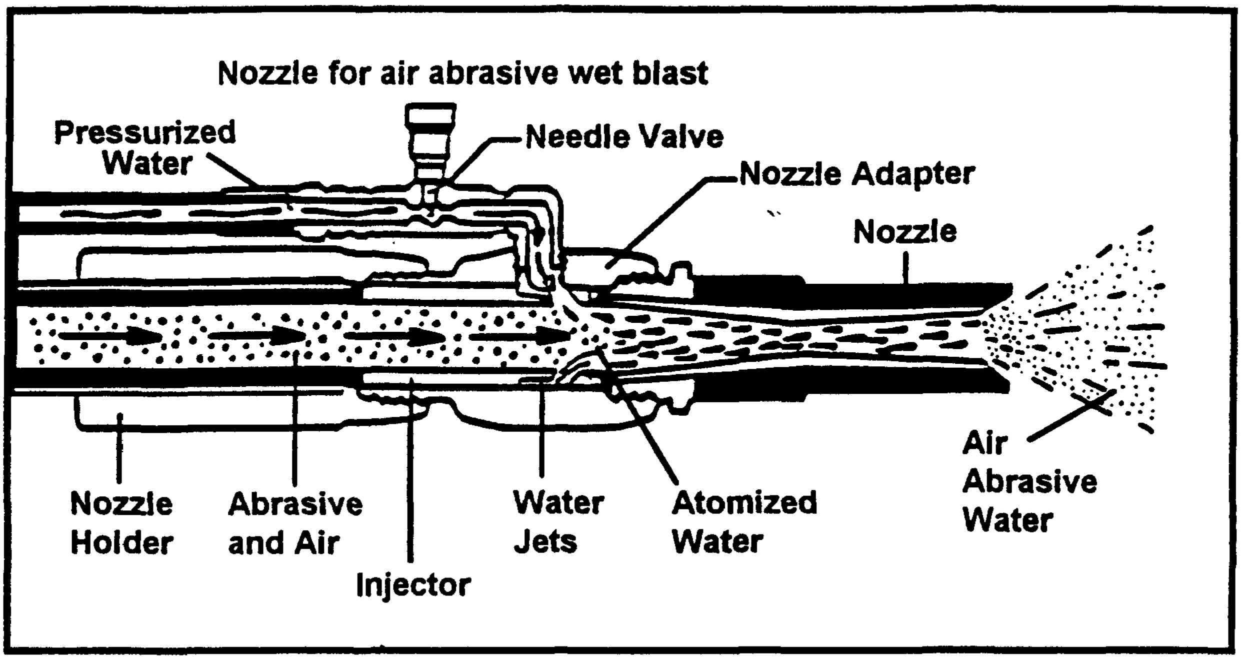

Figure 3-2. Nozzle for air abrasive wet blast.[17]

stream of water is a technique that was evaluated at Pearl Harbor Naval Shipyard but was not fully accepted because of its operational slowness, the fact that water promotes corrosion of bare metal, the requirement that a rust inhibitor be included in the jet stream (rust inhibitors may be pollutants), the high initial cost of equipment, and the fact that the operation will not blast to white metal. In Northern shipyards, antifreeze additives would have to be added, and these additives may be water pollutants. The advantage of high-pressure water blasting is that it reduces air pollution.[14]

If abrasives are introduced to a high-pressure water blast system, high-pressure water and abrasive blasting is provided. As compared to dry blasting, all wet blasting techniques produce substantially lower dust emissions.

3.4.1.1.6 Improved abrasives. There is an on-going study at shipyards to find better abrasives. Abrasives can be improved by ensuring that they are screened to remove dust emissions prior to being purchased. Hunters Point Naval Shipyard has changed to commercial Green Diamond™ to reduce the dust problem; however, complete elimination of dust is improbable. Norfolk Shipbuilding and Drydock Corporation (NORSHIPCO) has evaluated several blast media for paint removal, including garnet and baking soda.[16] The friability, or disintegration tendency, of abrasive grit can be selected to minimize particulate emissions and to make reclamation economical; however, friability must be traded off with costs and effectiveness and with the hardness of the grit chosen to prevent metal surface damage.

3.4.1.1.7 Water cleaning. Underwater cleaning of a ship's hull is normally accomplished by mechanically brushing the marine growth from the hull surface, but this method is only partially effective. This operation is not meant to remove paint, but it does significantly reduce the amount of blasting required before repainting, thereby reducing the level of emissions. Like underwater cleaning, water cleaning a vessel immediately after drydocking will remove some marine growth and help reduce abrasive blasting requirements.

3.4.1.2 Technologies Under Development.

3.4.1.2.1 SCHLICK blast cleaning systems. SCHLICK has developed a line of blast cleaning systems that are presently operated in European shipyards only. The "Mubid" is an automatic cleaning unit used in drydocks that is capable of cleaning dirt and debris from the ship's hull. It can also be used to remove marine fouling and rust from the bottom of the ship using high-pressure water blasting and abrasive blasting with wire shot as the blast medium. This unit can operate with as little as 1.4 meters (55.5 inches) of clearance between the drydock floor and the bottom of the hull. A new system, the "Model 3770 Dust Free Ship Cleaning System," is a device that cleans dirt, marine fouling, and rust from ship hulls using the same blasting techniques as the Mubid system. Particulate emissions and toxic waste are supposed to be reduced when using this device because it is equipped with a dust and debris capture unit. Other units developed by SCHLICK include a manual blast cleaning and recovery capsule, a portable recovery unit (Model VC-4000), a portable large-volume blasting unit (Model G-7) for use in areas where the 3770 model cannot clean, and a ship deck turbine wheel (Roto-Jet Model AB-9) for deck cleaning.[11]

3.4.1.2.2 Portable enclosure system. A self-supporting portable enclosure under development by Metro Machine Corporation is depicted in Figure 3-3. This system is designed specifically to control particulate matter emissions from abrasive blasting of ship hulls. However, as discussed in Section 3.2.3, it has potential to control VOC emissions from painting operations. The enclosure must be ventilated during use. Dead air space in corners, which can lead to fugitive emissions and particulates in the worker's visibility zone, are minimized with downdraft air circulation.

In the Metro Machine design, portable enclosures will cover small portions of the ship's hull at any given time; multiple units can be used concurrently. Metro Machine Corporation estimates that 80 to 85 percent of the typical hull can be accessed with the self-supporting mobile enclosures. However,

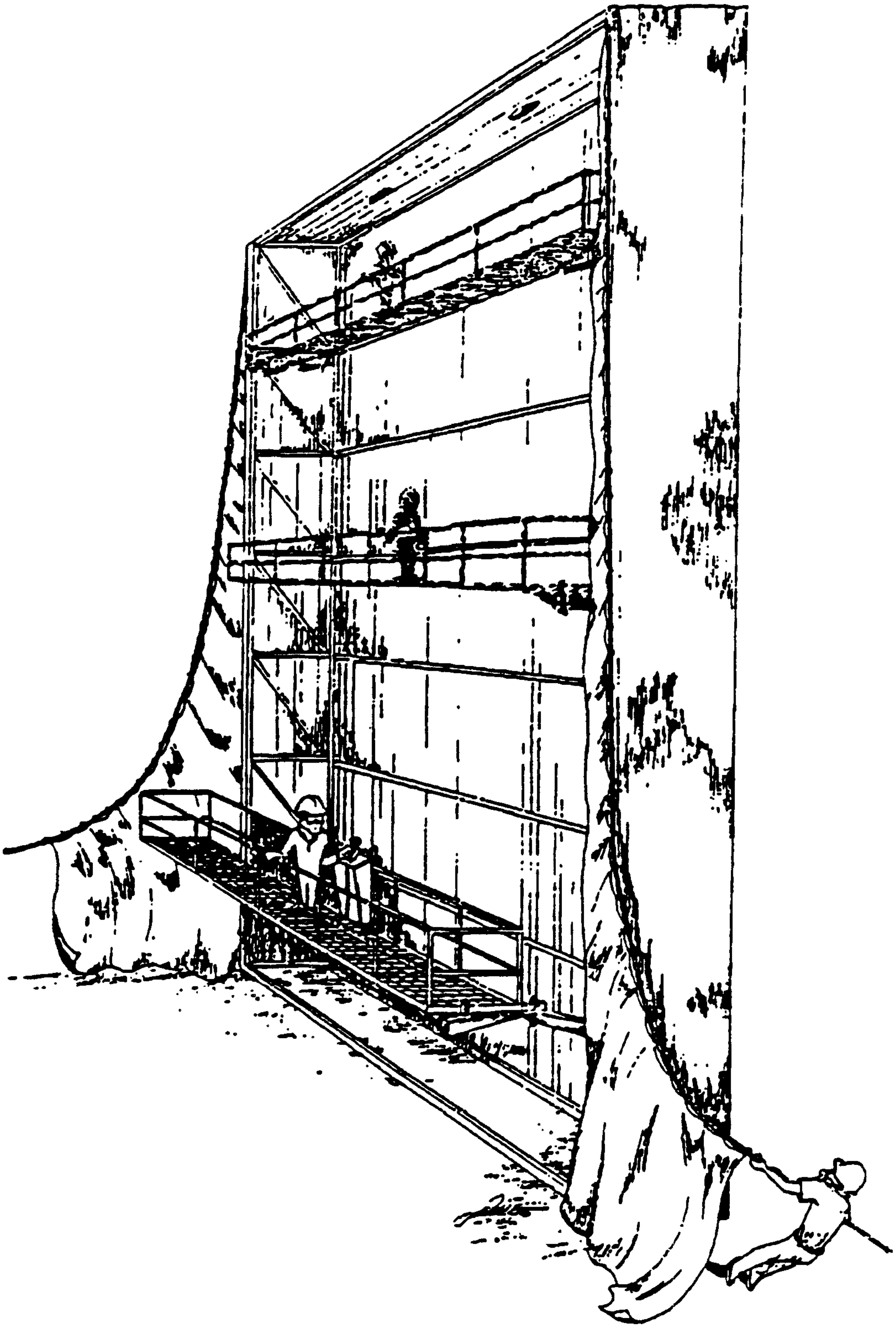

Figure 3-3. Portable enclosure.[5]

remote areas of the hull are usually difficult to enclose with these enclosures. The enclosures are moved from one area of a ship to another by crane.

The enclosures will be available in a variety of shapes and sizes and must have a certain amount of flexibility in their range of motions. Designs vary as to one-person or two-person platforms, depending upon the work application. Sufficient air is supplied within the enclosure to maintain worker visibility.

Because the surface being blasted will be temporarily enclosed and therefore protected from the weather, increased work time is expected in certain weather conditions such as light rain (mist) or fog. The shape of the hull and the shipyard facilities dictate the support mechanism used for the enclosures. Units can be mounted to the drydock wing wall, supported from the drydock floor, or attached to a man-lift (cherry picker) for mobility.[5]

3.4.2 Potential PM-10 Emission Reductions. Potential PM-10 emission reductions from using any of the control mechanisms described above are difficult to quantify because no reliable source for estimating PM-10 emissions from uncontrolled and controlled sources is currently available. A comparison of emission data gathered for abrasive blasting of ship hulls versus other structures (see Table 2-11) revealed no apparent trends. For this reason, data gathered on nonsimilar applications cannot be used at this time to estimate emissions from shipyard abrasive blasting operations.[13]

Emission factors for PM-10 cannot be developed without appropriate source test data from shipyard abrasive blasting operations. An ambient monitoring test was conducted at NORSHIPCO on September 9, 1992. The results of this test revealed that PM-10 emissions occur during ship blasting operations.[19] However, emissions from further tests need to be quantified in order to develop appropriate emission factors. Even with source test data, developing emission factors within this industry is challenging because of the variability in the particle distribution of the blast media, the friability of both the coating and corrosion products being removed, and variable wind and climatic conditions.

3.5 QUALITY CONTROL

In addition to the control measures for painting and blasting operations outlined in the above sections, emissions of PM-10 and VOC may also be reduced by minimizing air exposure, limiting rework, and suspending painting and blasting activities when wind and weather conditions are unfavorable.

3.5.1 Minimizing Air Exposure

From an industry perspective, the lowest-impact approach to reducing VOC emissions is to change work practices to minimize the opportunities for emissions. Section 3.3 discussed how emissions from cleaning solvents can be reduced by work practice modifications. Emissions of VOC's from paints and solvents (i.e., cleaning compounds, thinners, etc.) can also be controlled by limiting the quantities intentionally exposed to air. Using training and other programs to inform employees of good work practices would be necessary to implement such measures.

3.5.2 Limiting Rework

Rework may be required because of improperly prepared surfaces, inclement weather conditions that disrupt painting schedules, or other scheduling errors that result in improper paint application procedures. The cost of rework in any shipyard is so high that it is continually being addressed through the improvement of production techniques and processes. Continued awareness of the level of rework occurring in a shipyard and the relationships with paint usage, blast media usage, and their associated emissions would help in reducing emissions from these sources. Improved recordkeeping practices would help in tracking rework and the associated emissions.

3.5.3 Suspending Painting and Blasting Activities

Paint overspray and PM-10 emissions can be controlled to a limited extent by monitoring wind speed and by suspending painting and blasting activities when wind speed exceeds some preselected value. Resulting emission reductions are difficult to quantify, and emission credits cannot be given to a facility for following such a practice. However, improvements in air quality at nearby residential areas are often obvious when blasting is halted.

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4.0 MODEL SHIPYARDS AND EMISSION ESTIMATES

This chapter describes the models that have been developed to characterize the shipbuilding and ship repair industry, their corresponding emission estimates, and the methods used to determine these estimates. Due to the nature of this industry and its sporadic painting operations, an individual shipyard can fall in and out of a given model yard description. The model yards represent various practices within the shipbuilding and ship repair industry. However, due to the diverse nature of the industry, many shipbuilding and ship repair yards have developed specialized marketing niches that are not easily represented by a model yard approach. For these reasons, the model yards have been developed to represent the shipbuilding and ship repair industry as a whole; they do not necessarily represent every existing shipyard. These model yards will be used to evaluate the costs and environmental and energy impacts of control options on the affected sources. The majority of the existing yards have no controls for volatile organic compounds (VOC's) or particulate matter less than 10 micrometers in diameter (PM-10) on their outdoor operations; therefore, model yards represent uncontrolled operations.

Section 4.1, Model Yards, elaborates on the types of model yards, their corresponding sizes, and their overall coating, solvent, and blast media usage rates. Emission estimates are discussed in Section 4.2, and the references used to develop this information are listed in Section 4.3.

4.1 MODEL SHIPYARDS

Model yard development was based primarily on 1990 and 1991 information gathered from responses to information requests sent to shipbuilding and ship repair yards pursuant to Section 114 of the Clean Air Act, EPA's information-gathering authority.[1] Information gathered from coating manufacturers' Section 114 survey responses and site visit reports was used to supplement the data gathered from the shipyard survey responses.[2,3] A total of 25 private shipyard responses and 8 Naval repair yard Section 114 responses were used as the major source for developing model yards. These shipyards are listed in Table 4-1. In addition, nine coating manufacturer responses were received, and several shipyards (including one Naval repair yard) were visited to observe yard operations.

4.1.1 Description of Model Yards

Several key variables were considered in developing model yards. The type of vessel coated--military or commercial--is of primary importance because of different performance constraints. The type of ship operation--repair or construction--is important because painting and blasting operations differ between these two types of yards. The location of the painting and blasting operations within a yard affect the control options. Finally, the size of the model yard is another key factor that affects the economics of the control options.

Table 4-2 describes the eight model yards developed to characterize the industry. The models are divided into two main categories based on the type of work typically conducted, construction or repair. Within these two categories, the yards are segregated further by size. A more detailed discussion of model yard development is provided in Appendix B.

4.1.2 Model Yard Sizes

Four size classifications for construction and repair yards were developed. The "extra-small" category consists of yards that emit less than 22,680 kilograms per year (kg/yr) (25 tons

TABLE 4-1. SHIPYARD SURVEY RESPONSES USED FOR MODEL YARD DEVELOPMENT[1]

Name	Location (City, State)
PRIVATE YARDS	
Bath Iron Works	Bath, Maine
Bath Iron Works	East Brunswick, New Jersey
Bath Iron Works	Portland, Maine
Campbell Industries	San Diego, California
Eastern Shipyards	Panama City, Florida
Equitable Shipyard	New Orleans, Louisiana
General Dynamics Corporation	Groton, Connecticut
Gretna Machine & Iron Works	Harvey, Louisiana
HBC Barge, Incorporated	Brownsville, Pennsylvania
Halter Marine-Lockport	Lockport, Louisiana
Halter Marine-Moss Point	Moss Point, Mississippi
Ingalls	Pascagoula, Mississippi
Jeffboat Industries	Jeffersonville, Indiana
Marco Shipyard	Seattle, Washington
Moss Point Marine	Escatawpa, Mississippi
National Steel & Shipbuilding Corporation	San Diego, California
Newport News Shipbuilding	Newport News, Virginia
Norfolk Shipbuilding & Drydock Corporation	Norfolk, Virginia
Northwest Marine	Portland, Oregon
Peterson Builders	Sturgeon Bay, Wisconsin
Southwest Marine	San Diego, California
Southwest Marine	San Francisco, California
Todd Pacific Shipyard	Seattle, Washington
Trinity Beaumont	Beaumont, Texas
West State, Incorporated	Portland, Oregon
PUBLIC NAVAL YARDS	
Charleston Naval	Charleston, South Carolina
Long Beach Naval	Long Beach, California
Mare Island Naval	Valejo, California
Norfolk Naval	Norfolk, Virginia
Pearl Harbor Naval	Pearl Harbor, Hawaii
Philadelphia Naval	Philadelphia, Pennsylvania
Portsmouth Naval	Portsmouth, New Hampshire
Puget Sound Naval	Bremerton, Washington

TABLE 4-2. MODEL SHIPYARDS

	Model yard							
	Construction				Repair			
Model Yard No.	1	3	5	7	2	4	6	8
Size	Large	Medium	Small	Extra small	Large	Medium	Small	Extra small
Average total coating usage, L/yr (gal/yr)[a]	510,560 (134,876)	158,726 (41,931)	70,988 (18,753)	27,785 (7,340)	453,718 (119,860)	131,228 (34,667)	70,511 (18,627)	34,436 (9,097)
Average total solvent usage, L/yr (gal/yr)	162,132 (42,831)	43,532 (11,500)	10,845 (2,865)	14,415 (3,808)	23,091 (6,100)	20,562 (5,432)	1,893 (500)	10,224 (2,701)
Average total abrasive usage, kg/yr (tons/yr)	7.51×10^{7} (82,747)	2.30×10^{6} (2,530)	(N/A)[b]	9.03×10^{5} (995)	9.55×10^{6} (10,525)	4.03×10^{6} (4,442)	2.96×10^{6} (3,264)	4.01×10^{6} (4,420)

[a] Coating usage volumes are in units of liters per year (L/yr) and gallons per year (gal/yr) less water.

[b] Information not available.

per year [tons/yr]) of VOC's. The "small" category consists of yards that emit between 22,680 kg (25 tons) and less than 45,360 kg/yr (50 tons/yr) of VOC's. The "medium" category consists of yards that emit between 45,360 kg (50 tons) and less than 90,720 kg/yr (100 tons/yr) of VOC's, and the "large" category consists of yards that emit 90,720 kg/yr (100 tons/yr) or more of VOC's.

4.1.3 Model Yard Parameters

Table 4-2 summarizes the average total coating, solvent, and abrasive media usages for each model yard. These usages are the averages of the actual usage rates reported by the shipyards in Table 4-2.[1] The overall total coating and solvent usage for "construction yards" is greater than that of the "repair yards" for all but the extra small model yards. This is because there are significant differences between painting a ship during construction and repainting during repair operations. Ship construction requires the constant application of paint systems to various ship parts before, during, and after the ship is assembled. Repairing a ship requires repainting or spot repairing of ship areas, mainly the hulls. The frequency of repainting depends on many factors, including the ship owner's specifications.[4]

The model yards in Table 4-2 indicate that large construction yards use approximately eight times as much abrasive media as large repair yards. Ship construction requires the use of large amounts of blast media for surface preparation and blasting. The surface of ship parts must be prepared before initial painting to remove mill scale (rust) or any other materials that could interfere with the performance of the coating system. After coating systems have been applied to various ship parts, blasting usually takes place several times as the parts are assembled.

Repairing a ship usually requires less blast media because blasting occurs only on the portion of the ship to be repainted.[4] Table 4-2 indicates, however, that medium and extra-small repair yards use considerably more abrasive media than their construction yard counterparts. These apparent inconsistencies may be the result of incomplete information submitted by the shipyards, including blast media recovery rates, area blasted, and blast media effectiveness.

4.1.4 Relative Usages

Relative coating usages were determined for both construction and repair-type shipyards. In Table 4-3, a comparison of relative coating usage shows that repair yards use more antifoulants than do construction yards, and construction yards use more inorganic zincs and alkyds than do repair yards.[1] Repair yards use relatively more antifoulants because a greater proportion of their painting is on exterior ship hulls, which require antifoulant coatings. Construction yards use more inorganic zinc and alkyd coatings as anticorrosive primers and undercoats for painting interior surfaces and bare metal; repair yards are typically involved in very little interior-surface repainting. Epoxy coating usage is similar between the two types of yards. There are many types of epoxy resins, which increases their versatility for use as undercoats on all parts of a ship.

4.1.5 Average VOC Contents

Table 4-4 gives the weighted (normalized) average VOC content, i.e., the average VOC content weighted by volume used, for the five coating categories.[1,2] These averages were determined collectively for construction and repair yards because the yards use the same coatings, although not in the same relative quantities. The inorganic zinc coating category has the highest average VOC content; the general-use epoxy coating has the lowest.

4.2 VOC AND PM-10 EMISSIONS ESTIMATES

This section discusses the estimation of VOC and PM-10 emissions. Section 4.2.1 presents the VOC emission estimates for the eight model yards. The VOC emission calculations are based on relative usages and average VOC content data presented in Section 4.1. Section 4.2.2 provides details of why PM-10

TABLE 4-3. RELATIVE USAGES[1]

Category	Yard type	
	Construction, %	Repair, %
Specialty coatings		
Antifoulant	4.0	22.3
Inorganic zinc	15.0	0.7
Other specialty	9.8	11.8
General-use coatings		
Alkyd based	16.6	2.4
Epoxy based	54.6	62.8
TOTAL	100.0	100.0

TABLE 4-4. AVERAGE VOC CONTENTS[1,2]

Category	Average VOC content	
	g/L, less water	lb/gal, less water
Specialty coatings		
Antifoulant	387	3.23
Inorganic zinc	544	4.54
Other specialty	425	3.55
General-use coatings		
Alkyd based	473	3.95
Epoxy based	350	2.92
Thinning solvent	839[a]	7.00[a]

[a] The weighted average VOC content of reported solvents.

emissions could not be estimated for any of the eight model yards.

4.2.1 VOC Emission Estimates

Table 4-5 gives a breakdown of the VOC emissions by category for each model shipyard. Within each model, the VOC emissions for the various coating categories are the product of the average total coating usages, the relative usages in Table 4-3, and the weighted average VOC contents in Table 4-4. The VOC emissions estimated for the thinning solvent category are the product of the average total solvent usages, the percent solvent used for thinning, and the weighted average VOC content of 839 g/L (7.0 lb/gal) of reported solvents.

Table 4-5 shows that the major contributor of VOC emissions from both construction and repair operations is epoxy-based coatings (approximately 40 and 50 percent, respectively). Although epoxy-based coatings are comparatively low in VOC content, as indicated in Section 4.1.4, they are by far used in the greatest volume because of their versatility.

Overall, VOC emissions by coating/solvent category from both construction and repair operations are similar with the exception of VOC emissions from the use of antifoulant and inorganic zinc coatings. The VOC emissions from antifoulant coatings account for approximately 3 and 25 percent of VOC emissions from construction and repair operations, respectively, while the VOC emissions from inorganic zinc coatings account for approximately 16 and 1 percent of the total VOC emissions from construction and repair operations, respectively. On average, construction operations (based on overall coating usage) emit considerably more VOC's than do repair operations.

4.2.2 PM-10 Emissions From Abrasive Blast Media

Information on the amount of blast media used for surface preparation of ships was provided by 20 shipyards.[1,3,5] Table 4-5 does not, however, present estimated PM-10 emissions from abrasive blast media usage for the eight model yards because no correlation was found between blast media usage and PM-10 emissions. Further, it would be difficult to develop such a

TABLE 4-5. VOC EMISSION ESTIMATES FOR MODEL SHIPYARDS[a]

Yard type	Construction				Repair			
Size classification	Extra small	Small	Medium	Large	Extra small	Small	Medium	Large
Average total coating usage, L/yr (gal/yr)	27,785 (7,340)	70,988 (18,753)	158,726 (41,931)	510,560 (134,876)	34,436 (9,097)	70,511 (18,627)	131,228 (34,667)	453,718 (119,860)
Average total solvent usage, L/yr (gal/yr)	14,415 (3,808)	10,845 (2,865)	43,532 (11,500)	162,132 (42,831)	10,224 (2,701)	1,893 (500)	20,562 (5,432)	23,091 (6,100)
Percent used for thinning	50	40	20	50	20	3	20	20
Percent used for cleaning	50	60	80	50	80	97	80	80
VOC emissions by coating category, kg/yr (tons/yr)								
SPECIALTY:								
Antifoulant	400 (0.5)	1,100 (1.2)	2,500 (2.7)	7,900 (8.7)	3,000 (3.3)	6,100 (6.7)	11,300 (12.5)	39,000 (43.2)
Inorganic zinc	2,300 (2.5)	5,800 (6.4)	13,000 (14.3)	41,700 (45.9)	100 (0.1)	300 (0.3)	500 (0.6)	1,700 (1.9)
Other specialty	1,200 (1.3)	3,000 (3.3)	6,600 (7.3)	21,300 (23.5)	1,700 (1.9)	3,500 (3.9)	6,600 (7.3)	22,800 (25.1)
GENERAL USE:								
Alkyd based	2,200 (2.4)	5,600 (6.1)	12,500 (13.7)	40,100 (44.2)	400 (0.4)	800 (0.9)	1,500 (1.6)	5,200 (5.7)
Epoxy based	5,300 (5.9)	13,600 (14.9)	30,300 (33.4)	97,500 (107.5)	7,600 (8.3)	15,500 (17.1)	28,800 (31.8)	99,700 (109.9)
VOC emissions from thinning solvent, kg/yr (tons/yr):	6,000 (6.7)	3,600 (4.0)	7,300 (8.1)	68,000 (75.0)	1,700 (1.9)	50 (0.1)	3,500 (3.8)	3,900 (4.3)
TOTAL VOC EMISSIONS, kg/yr (tons/yr)	17,400 (19.3)	32,700 (35.9)	72,200 (79.5)	276,500 (304.8)	14,500 (15.9)	26,300 (29.0)	52,200 (57.6)	172,300 (190.1)

[a] All numbers in this table are independently rounded. As a result, metric and english units may not agree precisely.

correlation because PM-10 emissions in this industry are dependent upon a number of factors including wind and weather conditions during blasting, the type of blast medium used, and the material (e.g., paint and/or corrosion products) being removed from the ship surface.

The shipyards reported recovery of blast media at rates ranging from 50 to 99 percent.[5] However, the low recovery rates that were reported include media losses not related to air emissions. Typically, the bulk of the media falls to the floor of the drydock, where front-end loaders are used to remove the material for disposal. During the use and recovery of the media, an indeterminate quantity may be lost due to windblown entrainment or losses to the waste water system. An evaluation of media losses to air, water, and land based on a mass balance would be a significant undertaking given the imprecise use and recovery practices, and so far, none have been conducted at shipyards.

A discussion of existing data used to evaluate PM-10 emission factors is provided in Chapter 2. From this data it may be concluded that until emissions from further tests are quantified, appropriate emission factors cannot be developed.[6]

4.3 REFERENCES

1. Memorandum from deOlloqui, V., Midwest Research Institute (MRI), to Project File. Facilities in the Shipbuilding and Ship Repair Data Base. November 11, 1992.

2. Memorandum from deOlloqui, V., MRI, to Project File. List of Coating Manufacturers Surveyed. November 16, 1992.

3. Memorandum from Williamson, M., MRI, to Project file. List of Shipyard Site Visits. March 18, 1993.

4. VOC Emission Control Technologies for Ship Painting Facilities - Industry Characterization. Centec Corporation. Prepared for the U. S. Environmental Protection Agency, Cincinnati, Ohio. EPA 600/2-18-131. July 1981.

5. Memorandum from Harris, V., MRI, to L. Driver, ESD/CPB/CAS. Source Test Justification for Measuring PM-10 Emissions from Abrasive Blasting Operations at Shipyards. September 24, 1992.

6. Ambient Monitoring Test for Total Suspended and PM-10 Particulate Emissions During a Ship Sandblasting Operation. Norfolk Shipbuilding and Drydock Corporation, Norfolk, VA. Prepared by Industrial and Environmental Analysts, Inc., Morrisville, NC. September 9, 1992.

5.0 COSTS AND ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROL OPTIONS

This chapter presents the costs and VOC emission reductions associated with selected control strategies. The costs and emission reductions associated with the use of lower-VOC coatings are presented in Section 5.1. The VOC emission reductions and costs of using add-on controls to control spray booth and tank VOC emissions are presented in Sections 5.2 and 5.3, respectively. A discussion of why the costs and emission reductions of various strategies to reduce PM_{10} emissions from abrasive blasting operations could not be evaluated is in Section 5.4. Control costs for cleaning are presented in Section 5.5. The environmental and energy impacts of the various control strategies evaluated are presented in Section 5.6.

5.1 COST OF USING LOWER-VOC COATINGS FOR SHIPYARD COATING OPERATIONS

This section presents the methodology and results of the cost impact analysis for the use of lower-VOC coatings. Section 5.1.1 describes the three control scenarios evaluated, and Section 5.1.2 discusses the assumptions and costing inputs. The costs and associated emission reductions and the recordkeeping and reporting requirements are presented in Sections 5.1.3 and 5.1.4, respectively. The cost effectiveness of the three scenarios based on the information presented in Sections 5.1.1 through 5.1.4 is presented in Section 5.1.5.

5.1.1 Lower-VOC Control Options

Four lower-VOC control options were evaluated for each of the three major-use coating categories derived from the project coatings data base. These options are described in Table 5-1. The first two correspond to the 1992 and 1994 VOC limits contained in South Coast Air Quality Management District (SCAQMD) Rule 1106, Marine Coating Operations.[1] The other two were derived from the "project coatings data base" (data base), which was developed from data supplied by shipyards and supplemented by coating manufacturers' data. That information is somewhat dated since most facilities provided data on coatings used in 1990; a few from 1991.

TABLE 5-1. OPTIONS BASED ON USING LOWER-VOC COATINGS

Options	Type of Limit	Basis	Limits, VOC/L coating minus water and minus "exempt" solvents (lb VOC/gal coating minus water and minus "exempt" solvents)		
			General use	Antifoulant	Inorganic zinc
1	Never to be exceeded	1992 California limits (by paint category)	340 (2.83)	400 (3.33)	650 (5.40)
2	Never to be exceeded	1994 California limits (by paint category)	340 (2.83)	400 (3.33)	340 (2.83)
3	Weighted Average	Average of paints that meet 1994 California limits[a] (by paint category)	297 (2.48)	360 (3.00)	5 (0.04)
4	Never to be exceeded	Lowest VOC paint (by paint category)[b]	200 (1.67)	315 (2.62)	0

[a] Average VOC content (weighted by volume) of paints in the project data base that meet the 1994 California standards.

[b] Lowest VOC paint in the project data base with a minimum annual usage of 3,790 liters (1,000 gallons).

Note: For Options 3 and 4, the limits are based on the project coatings data base, which was developed primarily from 1990 data.

Two approaches to VOC limitations based on using lower-VOC coatings were considered. The first involves selecting a maximum or never-to-be-exceeded VOC limit for each coating category. The shipyard and coating manufacturer would know that by using or producing a coating that meets the limit(s), as applied, there would be no violation of the rule. Options 1, 2, and 4 in Table 5-1 involve such maximum or never-to-be-exceeded values for each coating category.

The second type would allow the shipyard to use a coating of any VOC content. However, planning, calculating, and recordkeeping are required to make certain the weighted average of the VOC content of all coatings in a category do not exceed the limit. Use of coatings with VOC contents above the average limit must be offset by use of ones with VOC contents lower than the average limit within the designated averaging period (e.g., during a quarter). Averages allow more flexibility, but at the price of a significant administrative workload. Option 3 designates weighted average VOC limits for the three coating categories.

The basis for the options presented in Table 5-1 can be further described as follows:

Option 1--Maximum limits for each coating category identical to the 1992 California limits;

Option 2--Maximum limits for each coating category identical to the 1994 California limits;

Option 3--An average limit for each coating category based on the weighted average VOC content of coatings within each category that comply with the 1994 California limits; and

Option 4--A maximum VOC limit for each coating category that would mandate use of coatings with no more VOC than the lowest VOC content used in significant volume in the data base for each category.

Options 1 and 2 differ only in the limit for inorganic zinc. The 1992 and 1994 levels contained in SCAQMD Rule 1106 are the same for antifoulants and general use coatings.

The average limits for each coating category in the third option were calculated as the weighted average VOC content of all the coatings in the data base that comply with the 1994

California limits.

The fourth option designates not-to-be-exceeded VOC contents for each of the three major-use coating categories based on the lowest-VOC coating in the data base for each category. In determining the lowest-VOC coating in each coating category, only those coatings with an aggregate reported usage of more than 3,790 L (1,000 gal) were considered. The calculation of the limits corresponding to the four options is described more fully in Appendix C.

All of the options in Table 5-1 are for coatings "as applied." The term "as applied" refers to the coating as it is applied to the substrate, after thinning. The information obtained in the surveys from shipyards and coating manufacturers pertained to "as supplied" coatings, i.e., before thinning. In evaluating the coatings in the data base against all of the "as applied" limits shown in Table 5-1, all coatings at or below the indicated levels were included. Thus, it was assumed that an "as-supplied" coating with a VOC content equal to those in the table could not be used if any solvent were added.

For options 1, 2, and 4, in evaluating the use of lower-VOC coatings, it was assumed that those yards currently using coatings with VOC contents greater than the limits shown in Table 5-1 would switch to coatings with VOC contents equal to the weighted average VOC content of the coatings in the coatings data base that meet the limits shown in Table 5-1. In other words, it was assumed that the distribution of the lower-VOC coatings would be similar to the usage distribution of the compliant coatings in the project data base. As stated previously, Option 3, places no constraint on coatings that can be used as long as the weighted average VOC content over the designated averaging period is less than the limit.

5.1.2 Assumptions and Scenarios Evaluated

Volatile organic compound emissions from the coating operation result from VOC inherent in the coatings and the solvent used to thin the coatings. Emissions of VOC's also result from cleaning. The reduction of VOC emissions from cleaning is discussed in Section 5.4. For this analysis, the reduction in VOC emissions that occurs with the use of lower-VOC coatings is calculated based on the following assumptions: (1) the VOC content of the coating is lower, and (2) less coating is used due to the increased solids content of the lower-VOC coating. For purposes of estimating costs, the total usage of thinning solvent decreases with the decreased coating usage because of the assumption 5% solvent is added to all coatings. These factors are described more in the following paragraphs and in Appendix C.

Emission reductions and costs were developed for baseline and for the lower-VOC options presented in Table 5-1. The parameters for coatings used in the impact analysis for baseline and lower-VOC options are based on information in the data base.[2,3] These coating parameters are summarized in Table 5-2. Baseline emissions correspond to emissions associated with the coatings used in the yards today as indicated by the data base. The VOC emissions were based on the organic solvents in the paint and thinner as indicated in Appendixes B and C.

For the impact analysis, it was assumed that the total build of the lower-VOC coating (the dry film thickness) would equal that of the conventional counterpart, and the total amount of solids applied per unit area of surface would remain constant.[4] Because the lower-VOC solventborne coatings have higher solids contents (on a percent volume basis), the total number of liters (gallons) applied to coat a given area is less than that for the conventional, lower-solids coatings (assuming constant transfer efficiency and constant paint film thickness).

The solids contents of the majority of the coatings was calculated using the equation described in Appendix C, which is not valid for coatings that contain more than trace quantities of water or "exempt" solvents. In a few cases where the equation (or associated assumption) produced unrealistically high solids contents, the maximum solids was established for each of the

TABLE 5-2. COATING PARAMETERS[a-c]

Coating	VOC limit, g/L-water (lb/gal-water)	Weighted average price, $/L ($/gal)	Weighted average VOC content, g/L-water (lb/gal-water)	Average weighted solids content, % vol
Antifoulant				
Baseline	None	9 (34)	387 (3.23)	54
Option 1 limit	400 (3.33)	9 (34)	344 (2.87)	59
Option 2 limit	400 (3.33)	9 (34)	344 (2.87)	59
Option 4 limit	315 (2.62)	9 (34)	306 (2.55)	63
Inorganic zinc				
Baseline	None	6 (22)	544 (4.54)	51
Option 1 limit	650 (5.40)	6 (22)	541 (4.51)	51
Option 2 limit	340 (2.83)	8 (29)	2 (0.02)	65
Option 4 limit	0 (0)	8 (29)	0 (0)	65
General use				
Baseline	None	4 (16)	368 (3.07)	57
Option 1 limit	340 (2.83)	5 (20)	275 (2.29)	65
Option 2 limit	340 (2.83)	5 (20)	275 (2.29)	65
Option 4 limit	200 (1.67)	5 (20)	178 (1.48)	70
Solvent	None	1 (4)	840 (7)	N/A[d]

[a] Development of these coating parameters is based on the shipyard and coating supplier survey responses and is described in more detail in Appendix C.

[b] Volatile organic compound content given in grams of VOC per liter of coating minus water (pounds of VOC per gallon of coating minus water), as applied.

[c] Numbers in this table are independently rounded.

[d] Not applicable.

three main coating categories based on data provided by coating suppliers.[5,6] The maximum solids content for antifoulants and inorganic zinc coatings was assumed to be 65 percent by volume and that of general use coatings was assumed 70 percent.

Actual solids data (based on product data sheets or Material Safety Data Sheets [MSDS's]) were available for the major-use inorganic zinc and alkyd coatings (part of the general use category). Solids data provided by the manufacturer were used for these coatings rather than the solids content calculated by the equation described in Appendix C.

In evaluating the use of lower-VOC solventborne coatings, three different scenarios were considered. The first assumed that lower-VOC coatings require the same amount of thinning solvent, gallon for gallon, as conventional coatings. Since fewer gallons of lower-VOC coatings are required because of their higher solids content, thinner use would also decrease.

In the second scenario, it was assumed that in-line paint heaters would be used rather than solvent to decrease the coating viscosity to the desired levels. This assumption was based on information supplied by vendors and shipyards that use in-line paint heaters.[7-10]

The third scenario used both in-line paint heaters and thinning solvent. The quantity of thinning solvent required was assumed to be the same as for the first scenario. These three scenarios were evaluated as options for shipyards that may have different requirements depending on the painting operation, the coatings used, and climatological conditions. For example, some yards may not be able to spray the higher-solids, lower-VOC coatings without reducing their viscosity. Ideally, in-line heaters will decrease the viscosity and thinning solvent will be unnecessary (Scenario 2). In some instances, heating alone will not be sufficient and some solvent may also be required (Scenario 3). For example, if a yard uses relatively long coating supply lines, during very cold weather it may not be possible to heat the coating enough to ensure the proper viscosity or pressure at the gun tip.[10] Clearly, however, shortening the distance between the gun and the paint container is a low cost option to solvent addition for viscosity control under freezing conditions as would spacing several heaters along the length of the supply line.

Based on information contained in the shipyard survey responses, the net cost associated with switching to lower-VOC coatings was assumed to be the sum of difference in cost of the coatings, the cost of in-line heaters, the savings associated with decreased thinner usage, the costs of additional recordkeeping and reporting requirements, and the cost of implementing new work practices. Some yards that had tested lower-VOC, higher-solids coatings indicated that they had to change spray guns because higher pressures were needed to atomize the new coatings. One yard indicated that higher solids coatings tended to clog the lines, requiring more purging and more cleaning time. Some yards indicated that it takes longer for the lower-VOC coatings to cure, which can slow down the coating operation overall. However, in the aggregate, there was no consensus on the need for different spray guns, additional purging, or increased cure times.[2] Therefore, these potential costs were not quantified.

5.1.3 Results of the Analysis

The emission reduction and costs associated with scenario 1 are presented in Tables 5-3 and 5-4. Scenario 2 emission reductions and costs are presented in Tables 5-5 and 5-6. Scenario 3 results are presented in Tables 5-7 and 5-8. The emission reductions and coating costs associated with option 3 are assumed to be the same as those of option 2, because both options are based on the 1994 California limits.

In all three scenarios, fewer gallons of higher solids coatings are required. The lower-VOC coatings, however, are more expensive on a dollar-per-gallon basis. The savings associated with the decreased volume requirements is more than offset by the higher price of the lower-VOC inorganic zincs and general use

TABLE 5-3a. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 1, kg/yr(a)(b)(c)
(METRIC UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr	27,781	70,988	158,726	510,560	34,436	70,511	131,228	453,718
Average total solvent use, L/yr	14,415	10,845	43,532	162,132	10,224	1,893	20,562	23,091
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 2	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 4	139	356	795	2,558	949	1,943	3,616	12,502
Inorganic Zinc								
Emission reduction Option 1	15	38	86	276	1	3	5	16
Emission reduction Option 2	2,261	5,778	12,919	41,556	187	383	712	2,462
Emission reduction Option 4	2,269	5,798	12,964	41,700	188	384	715	2,471
General Use								
Emission reduction Option 1	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 2	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 4	4,412	11,273	25,205	81,076	5,006	10,251	19,078	65,961
Thinner								
Emission reduction Option 1	549	331	664	6,178	169	5	341	382
Emission reduction Option 2	745	448	900	8,377	173	5	348	391
Emission reduction Option 4	1,028	619	1,242	11,562	265	7	533	598
Emission Reductions, metric tons/yr								
Emission reduction Option 1	3.2	7.0	15.5	54.0	3.6	7.0	13.3	45.1
Emission reduction Option 2	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Emission reduction Option 3	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Emission reduction Option 4	7.8	18.0	40.2	136.8	6.4	12.6	23.9	81.5

(a) Includes the use of lower-VOC coatings with thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-3b. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 1, lb/yr(a)(b)(c)
(ENGLISH UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, gal/yr	7,339	18,753	41,931	134,876	9,097	18,627	34,667	119,860
Average total solvent use, gal/yr	3,808	2,865	11,500	42,831	2,701	500	5,432	6,100
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	177	452	1,012	3,254	1,207	2,472	4,601	15,906
Emission reduction Option 2	177	452	1,012	3,254	1,207	2,472	4,601	15,906
Emission reduction Option 4	307	783	1,752	5,634	2,090	4,279	7,964	27,537
Inorganic Zinc								
Emission reduction Option 1	33	84	189	607	3	6	10	36
Emission reduction Option 2	4,981	12,727	28,456	91,533	412	843	1,568	5,423
Emission reduction Option 4	4,998	12,771	28,555	91,851	413	846	1,574	5,442
General Use								
Emission reduction Option 1	5,533	14,138	31,612	101,684	6,279	12,856	23,927	82,727
Emission reduction Option 2	5,533	14,138	31,612	101,684	6,279	12,856	23,927	82,727
Emission reduction Option 4	9,717	24,830	55,519	178,582	11,027	22,579	42,022	145,289
Thinner								
Emission reduction Option 1	1,210	728	1,461	13,608	373	10	750	842
Emission reduction Option 2	1,640	987	1,982	18,451	381	11	767	861
Emission reduction Option 4	2,264	1,363	2,735	25,466	583	16	1,173	1,318
Emission Reductions, tons/yr								
Emission reduction Option 1	3.5	7.7	17.1	59.6	3.9	7.7	14.6	49.8
Emission reduction Option 2	6.2	14.2	31.5	107.5	4.1	8.1	15.4	52.5
Emission reduction Option 3	6.2	14.2	31.5	107.5	4.1	8.1	15.4	52.5
Emission reduction Option 4	8.6	19.9	44.3	150.8	7.1	13.9	26.4	89.8

(a) Includes the use of lower-VOC coatings with thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-4. COSTS FOR LOWER-VOC SCENARIO 1, $/YR(a)(b)(c)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr (gal/yr)	27,781 (7,339)	70,988 (18,753)	158,726 (41,931)	510,560 (134,876)	34,436 (9,097)	70,511 (18,627)	131,228 (34,667)	453,718 (119,860)
Average total solvent use, L/yr (gal/yr)	14,415 (3,808)	10,845 (2,865)	43,532 (11,500)	162,132 (42,831)	10,224 (2,701)	1,893 (500)	20,562 (5,432)	23,091 (6,100)
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Additional cost Option 1	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 2	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 4	(1,426)	(3,643)	(8,147)	(26,204)	(9,721)	(19,904)	(37,044)	(128,079)
Inorganic Zinc								
Additional cost Option 1	0	0	0	0	0	0	0	0
Additional cost Option 2	830	2,121	4,741	15,251	69	140	261	904
Additional cost Option 4	830	2,121	4,741	15,251	69	140	261	904
General Use								
Additional cost Option 1	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 2	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 4	1,489	3,804	8,506	27,361	1,689	3,459	6,438	22,260
Thinner								
Additional cost Option 1	(622)	(374)	(752)	(6,998)	(192)	(5)	(386)	(433)
Additional cost Option 2	(844)	(508)	(1,019)	(9,489)	(196)	(5)	(394)	(443)
Additional cost Option 4	(1,164)	(701)	(1,407)	(13,097)	(300)	(8)	(603)	(678)
Net Cost ($/yr)								
Net cost Option 1	6,548	17,948	40,217	124,783	3,139	6,814	12,306	43,448
Net cost Option 2	7,157	19,935	44,691	137,543	3,203	6,954	12,559	44,342
Net cost Option 3	7,157	19,935	44,691	137,543	3,203	6,954	12,559	44,342
Net cost Option 4	(272)	1,580	3,694	1,280	(8,263)	(16,313)	(30,948)	(105,593)

(a) Includes the use of lower-VOC coatings with thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The costs for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-5a. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 2, kg/yr(a)(b)(c)
(METRIC UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr	27,781	70,988	158,726	510,560	34,436	70,511	131,228	453,718
Average total solvent use, L/yr	14,415	10,845	43,532	162,132	10,224	1,893	20,562	23,091
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 2	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 4	139	356	795	2,558	949	1,943	3,616	12,502
Inorganic Zinc								
Emission reduction Option 1	15	38	86	276	1	3	5	16
Emission reduction Option 2	2,261	5,778	12,919	41,556	187	383	712	2,462
Emission reduction Option 4	2,269	5,798	12,964	41,700	188	384	715	2,471
General Use								
Emission reduction Option 1	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 2	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 4	4,412	11,273	25,205	81,076	5,006	10,251	19,078	65,961
Thinner								
Emission reduction Option 1	5,446	3,278	6,578	61,253	1,511	42	3,038	3,412
Emission reduction Option 2	5,446	3,278	6,578	61,253	1,511	42	3,038	3,412
Emission reduction Option 4	5,446	3,278	6,578	61,253	1,511	42	3,038	3,412
Emission Reductions, metric tons/yr								
Emission reduction Option 1	8.0	9.9	21.5	109.1	4.9	7.0	16.0	48.2
Emission reduction Option 2	10.3	15.7	34.3	150.3	5.1	7.4	16.7	50.6
Emission reduction Option 3	10.3	15.7	34.3	150.3	5.1	7.4	16.7	50.6
Emission reduction Option 4	12.3	20.7	45.5	186.4	7.6	12.6	26.4	84.3

(a) Includes the use of lower-VOC coatings and in-line paint heaters. Thinner usage decreases to zero.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-5b. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 2, lb/yr(a)(b)(c)
(ENGLISH UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, gal/yr	7,339	18,753	41,931	134,876	9,097	18,627	34,667	119,860
Average total solvent use, gal/yr	3,808	2,865	11,500	42,831	2,701	500	5,432	6,100
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	177	452	1,012	3,254	1,207	2,472	4,601	15,906
Emission reduction Option 2	177	452	1012	3254	1207	2472	4601	15906
Emission reduction Option 4	307	783	1752	5634	2090	4279	7964	27537
Inorganic Zinc								
Emission reduction Option 1	33	84	189	607	3	6	10	36
Emission reduction Option 2	4981	12727	28456	91533	412	843	1568	5423
Emission reduction Option 4	4998	12771	28555	91851	413	846	1574	5442
General Use								
Emission reduction Option 1	5533	14138	31612	101684	6279	12856	23927	82727
Emission reduction Option 2	5533	14138	31612	101684	6279	12856	23927	82727
Emission reduction Option 4	9717	24830	55519	178582	11027	22579	42022	145289
Thinner								
Emission reduction Option 1	11,995	7,220	14,490	134,918	3,328	92	6,692	7,515
Emission reduction Option 2	11,995	7,220	14,490	134,918	3,328	92	6,692	7,515
Emission reduction Option 4	11,995	7,220	14,490	134,918	3,328	92	6,692	7,515
Emission Reductions, tons/yr								
Emission reduction Option 1	8.9	10.9	23.7	120.2	5.4	7.7	17.6	53.1
Emission reduction Option 2	11.3	17.3	37.8	165.7	5.6	8.1	18.4	55.8
Emission reduction Option 3	11.3	17.3	37.8	165.7	5.6	8.1	18.4	55.8
Emission reduction Option 4	13.5	22.8	50.2	205.5	8.4	13.9	29.1	92.9

(a) Includes the use of lower-VOC coatings and in-line paint heaters. Thinner usage decreases to zero.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-6. COSTS FOR LOWER-VOC SCENARIO 2, \$/YR(a)(b)(c)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr (gal/yr)	27,781 (7,339)	70,988 (18,753)	158,726 (41,931)	510,560 (134,876)	34,436 (9,097)	70,511 (18,627)	131,228 (34,667)	453,718 (119,860)
Average total solvent use, L/yr (gal/yr)	14,415 (3,808)	10,845 (2,865)	43,532 (11,500)	162,132 (42,831)	10,224 (2,701)	1,893 (500)	20,562 (5,432)	23,091 (6,100)
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Additional cost Option 1	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 2	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 4	(1,426)	(3,643)	(8,147)	(26,204)	(9,721)	(19,904)	(37,044)	(128,079)
Inorganic Zinc								
Additional cost Option 1	0	0	0	0	0	0	0	0
Additional cost Option 2	830	2,121	4,741	15,251	69	140	261	904
Additional cost Option 4	830	2,121	4,741	15,251	69	140	261	904
General Use								
Additional cost Option 1	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 2	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 4	1,489	3,804	8,506	27,361	1,689	3,459	6,438	22,260
Thinner								
Additional cost Option 1	(6,169)	(3,713)	(7,452)	(69,386)	(1,711)	(48)	(3,442)	(3,865)
Additional cost Option 2	(6,169)	(3,713)	(7,452)	(69,386)	(1,711)	(48)	(3,442)	(3,865)
Additional cost Option 4	(6,169)	(3,713)	(7,452)	(69,386)	(1,711)	(48)	(3,442)	(3,865)
Heaters annual cost (\$)	24,978	35,385	56,894	137,379	26,366	35,385	48,568	123,502
Net cost Option 1	25,980	49,995	90,411	199,774	27,985	42,157	57,818	163,518
Net cost Option 2	26,810	52,115	95,152	215,025	28,054	42,297	58,079	164,422
Net cost Option 3	26,810	52,115	95,152	215,025	28,054	42,297	58,079	164,422
Net cost Option 4	19,702	33,953	54,543	84,400	16,692	19,033	14,782	14,721

(a) Includes the use of lower-VOC coatings and in-line paint heaters. Thinner usage decreases to zero.

(b) Coating parameters in Table 5-2.

(c) The costs for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 *because both options are based on the 1994 California limits.*

TABLE 5-7a. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 3, kg/yr(a)(b)(c) (METRIC UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr	27,781	70,988	158,726	510,560	34,436	70,511	131,228	453,718
Average total solvent use, L/yr	14,415	10,845	43,532	162,132	10,224	1,893	20,562	23,091
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 2	80	205	459	1,477	548	1,122	2,089	7,222
Emission reduction Option 4	139	356	795	2,558	949	1,943	3,616	12,502
Inorganic Zinc								
Emission reduction Option 1	15	38	86	276	1	3	5	16
Emission reduction Option 2	2,261	5,778	12,919	41,556	187	383	712	2,462
Emission reduction Option 4	2,269	5,798	12,964	41,700	188	384	715	2,471
General Use								
Emission reduction Option 1	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 2	2,512	6,419	14,352	46,165	2,851	5,837	10,863	37,558
Emission reduction Option 4	4,412	11,273	25,205	81,076	5,006	10,251	19,078	65,961
Thinner								
Emission reduction Option 1	549	331	664	6,178	169	5	341	382
Emission reduction Option 2	745	448	900	8,377	173	5	348	391
Emission reduction Option 4	1,028	619	1,242	11,562	265	7	533	598
Emission Reductions, metric tons/yr								
Emission reduction Option 1	3.2	7.0	15.5	54.0	3.6	7.0	13.3	45.1
Emission reduction Option 2	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Emission reduction Option 3	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Emission reduction Option 4	7.8	18.0	40.2	136.8	6.4	12.6	23.9	81.5

(a) Includes the use of lower-VOC coatings with in-line paint heaters and thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-7b. EMISSION REDUCTIONS FOR LOWER-VOC SCENARIO 3, lb/yr(a)(b)(c)
(ENGLISH UNITS)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, gal/yr	7,339	18,753	41,931	134,876	9,097	18,627	34,667	119,860
Average total solvent use, gal/yr	3,808	2,865	11,500	42,831	2,701	500	5,432	6,100
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Emission reduction Option 1	177	452	1,012	3,254	1,207	2,472	4,601	15,906
Emission reduction Option 2	177	452	1,012	3,254	1,207	2,472	4,601	15,906
Emission reduction Option 4	307	783	1,752	5,634	2,090	4,279	7,964	27,537
Inorganic Zinc								
Emission reduction Option 1	33	84	189	607	3	6	10	36
Emission reduction Option 2	4,981	12,727	28,456	91,533	412	843	1,568	5,423
Emission reduction Option 4	4,998	12,771	28,555	91,851	413	846	1,574	5,442
General Use								
Emission reduction Option 1	5,533	14,138	31,612	101,684	6,279	12,856	23,927	82,727
Emission reduction Option 2	5,533	14,138	31,612	101,684	6,279	12,856	23,927	82,727
Emission reduction Option 4	9,717	24,830	55,519	178,582	11,027	22,579	42,022	145,289
Thinner								
Emission reduction Option 1	1,210	728	1,461	13,608	373	10	750	842
Emission reduction Option 2	1,640	987	1,982	18,451	381	11	767	861
Emission reduction Option 4	2,264	1,363	2,735	25,466	583	16	1,173	1,318
Emission Reductions, tons/yr								
Emission reduction Option 1	3.5	7.7	17.1	59.6	3.9	7.7	14.6	49.8
Emission reduction Option 2	6.2	14.2	31.5	107.5	4.1	8.1	15.4	52.5
Emission reduction Option 3	6.2	14.2	31.5	107.5	4.1	8.1	15.4	52.5
Emission reduction Option 4	8.6	19.9	44.3	150.8	7.1	13.9	26.4	89.8

(a) Includes the use of lower-VOC coatings with in-line paint heaters and thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The emission reductions for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

TABLE 5-8. COSTS FOR LOWER-VOC SCENARIO 3, $/YR(a)(b)(c)

	MODEL YARD							
	CONSTRUCTION				REPAIR			
	EXT. SMALL	SMALL	MEDIUM	LARGE	EXT. SMALL	SMALL	MEDIUM	LARGE
Average total coating usage, L/yr (gal/yr)	27,781 (7,339)	70,988 (18,753)	158,726 (41,931)	510,560 (134,876)	34,436 (9,097)	70,511 (18,627)	131,228 (34,667)	453,718 (119,860)
Average total solvent use, L/yr (gal/yr)	14,415 (3,808)	10,845 (2,865)	43,532 (11,500)	162,132 (42,831)	10,224 (2,701)	1,893 (500)	20,562 (5,432)	23,091 (6,100)
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Antifoulant								
Additional cost Option 1	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 2	(846)	(2,161)	(4,833)	(15,545)	(5,767)	(11,808)	(21,975)	(75,979)
Additional cost Option 4	(1,426)	(3,643)	(8,147)	(26,204)	(9,721)	(19,904)	(37,044)	(128,079)
Inorganic Zinc								
Additional cost Option 1	0	0	0	0	0	0	0	0
Additional cost Option 2	830	2,121	4,741	15,251	69	140	261	904
Additional cost Option 4	830	2,121	4,741	15,251	69	140	261	904
General Use								
Additional cost Option 1	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 2	8,016	20,484	45,802	147,326	9,097	18,627	34,667	119,860
Additional cost Option 4	1,489	3,804	8,506	27,361	1,689	3,459	6,438	22,260
Thinner								
Additional cost Option 1	(622)	(374)	(752)	(6,998)	(192)	(5)	(386)	(433)
Additional cost Option 2	(844)	(508)	(1,019)	(9,489)	(196)	(5)	(394)	(443)
Additional cost Option 4	(1,164)	(701)	(1,407)	(13,097)	(300)	(8)	(603)	(678)
Heater annual cost ($)	24,978	35,385	56,894	137,379	26,366	35,385	48,568	123,502
Net cost Option 1	31,526	53,333	97,111	262,162	29,505	42,199	60,874	166,950
Net cost Option 2	32,135	55,320	101,585	274,922	29,569	42,339	61,127	167,844
Net cost Option 3	32,135	55,320	101,585	274,922	29,569	42,339	61,127	167,844
Net cost Option 4	24,706	36,965	60,588	140,689	18,103	19,072	17,620	17,609

(a) Includes the use of lower-VOC coatings with in-line paint heaters and thinner usage equal to a constant percentage of total coating usage.

(b) Coating parameters in Table 5-2.

(c) The costs for Option 3 in each of the categories are assumed to be the same as those indicated for Option 2 because both options are based on the 1994 California limits.

coatings. However, there is a net savings in coating costs for antifoulants. Because all three scenarios presume the same lower-VOC coatings, the decrease in coating usage is the same for all three scenarios. Therefore, the additional cost of the paint is constant.

In the first scenario, thinner usage remains a constant percentage of total coating use. The costs for this scenario include the costs of the lower-VOC coatings and savings from decreased thinner usage. (The decrease results from the decrease in the volume of coating usage required.)

In the second scenario, in-line heaters are used with the lower-VOC coatings, eliminating the need for thinner. The costs for this scenario are lower-VOC coatings, savings from decreased thinner usage, and in-line heaters. The annualized in-line heater costs include capital recovery, maintenance and indirect costs, and the cost of electricity. The annualized heater costs are described more fully in Appendix C.

Scenario 3 involves the use of lower-VOC coatings, thinning solvent, and in-line heaters. The costs of the coatings, thinner, and heaters for scenario 3 were calculated as described above for scenarios 1 and 2.

The total emission reduction that is achieved under each of the scenarios is the sum of two components: (1) the emission reduction directly related to the use of lower-VOC paints and (2) the emission reduction that results from decreased thinner usage. The emission reductions directly associated with the lower-VOC coatings are the same for all three scenarios because all presume the same coatings are used. Under all three scenarios, additional emission reductions are achieved (relative to baseline) because less thinner is used. The reduction in thinner usage and the associated emission reduction are identical under scenarios 1 and 3. A greater emission reduction is achieved under scenario 2 because all thinner is eliminated.

5.1.4 Recordkeeping and Reporting Requirements

To gather information on the recordkeeping and reporting requirements currently in effect in this industry, current regulations were reviewed and a limited number of shipyards were contacted.[11-16] The recordkeeping and reporting practices currently used in this industry represent those needed to comply with permit conditions, and in some instances, the requirements of section 313 of the Superfund Amendments and Reauthorization Act of 1986 (SARA 313). The recordkeeping requirements and associated costs to comply with existing permits and SARA 313 requirements in areas without marine coating regulations are considered to represent baseline.

Options 1, 2, and 4 represent never-to-be-exceeded (or maximum) limits on the VOC contents of the coatings. Complying with maximum limits will require more involved recordkeeping practices than those necessary at the baseline.

Option 3 establishes weighted average VOC contents for each of the coating categories. Complying with this limit is even more involved than complying with the maximum limits established in options 1, 2, and 4. Extensive planning, recordkeeping, and reporting are required.

This section discusses the recordkeeping and reporting requirements and the associated costs developed for baseline, maximum limits, and average limits. Section 5.1.4.1 discusses the assumptions and various inputs used to develop the recordkeeping and reporting requirements, and Section 5.1.4.2 provides and elaborates on the associated costs. Additional detail on recordkeeping and reporting costs is presented in Appendix C.

5.1.4.1 Assumptions and Inputs. Information gathered from shipyards indicates that there is no distinct difference between the recordkeeping and reporting practices at construction versus repair yards.[14-16] Therefore, model yard recordkeeping and reporting requirements presented in this section are based on model yard size only. Because the same paints are used under all three of the scenarios introduced in Section 5.1.2, it is assumed that recordkeeping and reporting costs are identical for all three scenarios.

Recordkeeping and reporting costs are a function of the equipment and labor required. Equipment includes computer hardware and software. Labor is required to train the workers in the recordkeeping procedures, to record the necessary data in the field, to aggregate and manipulate the data, and to prepare the required reports.

Baseline. At baseline, most large and medium shipyards already maintain records to comply with State or local permits as well as SARA 313 requirements. It is assumed the operations at these facilities are complex enough to require a computerized system for recordkeeping and reporting. In contrast, small and extra small yards typically are both too small to be subject to SARA 313 requirements or significant permit conditions. As a result, small and extra small model yards are assigned no equipment costs at baseline.

The reporting requirements for large and medium yards at baseline are assumed to consist of an annual SARA 313 report and an annual report of VOC emissions. To prepare these reports, it is assumed that the facilities have adapted their central inventory tracking system to record the quantity of each paint and thinner used at the yard. This information is coupled with a data base in which the toxics and VOC contents of each paint and thinner are stored. The total technical labor devoted to baseline recordkeeping and reporting for large and medium yards is estimated to be 159 hours per year (hr/yr). Additional detail on this estimate is presented in Appendix C. Because small and extra small facilities are not typically subject to SARA 313 or other reporting requirements, the baseline labor assigned to these model yards is 0 hr/yr.

Maximum limits. To comply with maximum limits (Options 1, 2, and 4), it is assumed that no additional equipment beyond baseline is required for any model facility. Large and medium yards do not need to purchase new equipment because the equipment required at baseline is adequate for this purpose. Small and extra small yards are assumed not to need equipment because their operations are simple enough to be tracked manually.

Significant recordkeeping and reporting labor is required to meet a maximum VOC limit. For this analysis, it is assumed that records must be kept on a daily basis (consistent with EPA policy on VOC emissions averaging periods and enforcement) and compiled weekly. Quarterly reports are assumed, as are initial and refresher training sessions for the employees involved in recordkeeping. Estimates of the total technical labor for recordkeeping and reporting range from 145 hr/yr for extra small yards up to 1,274 hr/yr for large yards. (See Appendix C for additional information.)

Average limits. Complying with an average VOC limit (option 3) is more involved than complying with a maximum limit. For this reason, it is assumed that even small and extra small facilities will need computer equipment to meet an average limit. The baseline equipment is expected to be adequate for large and medium yards to comply with an average limit.

The labor associated with an average limit is estimated at twice the level of effort necessary for a maximum limit. This estimate reflects the extensive advance work that is necessary to plan, schedule, and track production and paint/solvent usage to meet an average limit. On this basis, technical labor for option 3 is estimated to range from 290 hr/yr for the extra small model yard to 2,548 hr/yr for the large model yard. (See Appendix C for additional information.)

5.1.4.2 Costs of Recordkeeping and Reporting. Table 5-9 shows the model yard costs developed for the recordkeeping and reporting requirements for baseline, maximum limits (options 1, 2, and 4), and average limits (option 3). The final recordkeeping and reporting costs were developed based on hour and labor rates from the Emission Standards Division (ESD) Regulatory Procedures Manual.[17] These rates are summarized in

TABLE 5-9. RECORDKEEPING AND REPORTING COSTS (INCREMENTAL COSTS ABOVE BASELINE), $/yr[a]

	Model yard							
	Construction				Repair			
	Extra small	Small	Medium	Large	Extra small	Small	Medium	Large
Baseline								
Labor	0	0	5,875	5,875	0	0	5,875	5,875
Equipment	0	0	1,400	1,400	0	0	1,400	1,400
Total	0	0	7,275	7,275	0	0	7,275	7,275
Options 1, 2, and 4 (Maximum limits)								
Labor	5,358	12,969	22,429	47,074	5,358	12,969	22,429	47,074
Equipment	0	0	1,400	1,400	0	0	1,400	1,400
Total	5,358 (5,358)	12,969 (12,969)	23,829 (16,554)	48,474 (41,199)	5,358 (5,358)	12,969 (12,969)	23,829 (16,554)	48,474 (41,199)
Option 3 (Average limit)								
Labor	10,716	25,938	44,858	94,148	10,716	25,938	44,858	94,148
Equipment	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
Total	12,116 (12,116)	27,338 (27,338)	46,258 (38,983)	95,548 (88,273)	12,116 (12,116)	27,338 (27,338)	46,258 (38,983)	95,548 (88,273)

[a] The costs in parentheses represent the incremental costs for recordkeeping and reporting above the costs of these activities incurred under baseline requirements.

calculations are presented in Appendix C.

5.1.5 Cost Effectiveness of Lower-VOC Control Options

The cost effectiveness (cost per mass of VOC controlled) of the four lower-VOC control options under scenarios 1, 2, and 3 are presented in Tables 5-11a, 5-11b, and 5-11c, respectively. Only incremental costs above baseline are presented in these tables. The cost effectiveness values were calculated based on the emission reductions and the costs of the control options relative to baseline. The emission reductions for the four control options are presented in Tables 5-3 (scenario 1), 5-5 (scenario 2), and 5-7 (scenario 3). The costs relative to baseline for the four control options are the sum of the coating-related costs (Tables 5-4, 5-6, and 5-8 for scenarios 1, 2, and 3, respectively) and the recordkeeping and reporting incremental costs (Table 5-9). For each option, the total incremental cost relative to baseline was divided by the emission reduction to obtain the cost effectiveness.

TABLE 5-10. HOUR AND LABOR RATES FOR RECORDKEEPING AND REPORTING

Type of Labor	Hour rate	Labor rate
Technical	(A)	$33/hr
Management	0.05 (A)	$49/hr
Clerical	0.10 (A)	$15/hr

Comparison of scenarios. The cost-effectiveness tables show that total costs progressively increase from scenario 1 through scenario 3 for all four control options. Accordingly, cost effectiveness generally becomes progressively less favorable (i.e., the $/Mg [$/ton] increases) from scenario 1 through scenario 3 for all four control options. (The exception is that cost effectiveness is more favorable for large construction yards

TABLE 5-11a. COST EFFECTIVENESS FOR LOWER-VOC SCENARIO 1(a)

	Model yard							
	Construction				Repair			
	Extra small	small	medium	large	Extra small	small	medium	large
Option 1								
Total emission reductions, Mg/yr	3.2	7.0	15.5	54.0	3.6	7.0	13.3	45.1
Costs, $/yr								
Additional coating	6,548	17,948	40,217	124,783	3,139	6,814	12,306	43,448
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	11,906	30,917	56,771	165,982	8,497	19,783	28,860	84,647
Option 2								
Total emission reductions, Mg/yr	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Costs, $/yr								
Additional coating	7,157	19,935	44,691	137,543	3,203	6,954	12,559	44,342
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	12,515	32,904	61,245	178,742	8,561	19,923	29,113	85,541
Option 3								
Total emission reductions, Mg/yr	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Costs, $/yr								
Additional coating	7,157	19,935	44,691	137,543	3,203	6,954	12,559	44,342
Additional recordkeeping	12,116	27,338	38,983	88,273	12,116	27,338	38,983	88,273
TOTAL COSTS	19,273	47,273	83,674	225,816	15,319	34,292	51,542	132,615
Option 4								
Total emission reductions, Mg/yr	7.8	18.0	40.2	136.8	6.4	12.6	23.9	81.5
Costs, $/yr								
Additional coating	(272)	1,580	3,694	3,310	(8,263)	(16,313)	(30,948)	(105,593)
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	5,086	14,549	20,248	44,509	(2,905)	(3,344)	(14,394)	(64,394)
Cost effectiveness, $/Mg								
Option 1	3,721	4,417	3,663	3,074	2,360	2,826	2,170	1,877
Option 2	2,235	2,571	2,141	1,833	2,253	2,729	2,080	1,797
Option 3	3,442	3,693	2,926	2,316	4,031	4,698	3,682	2,786
Option 4	652	808	504	325	(454)	(265)	(602)	(790)

(a)Example calculation for Option 1: For extra small yards, $11,906/yr / 3.2 Mg/yr = $3,721/Mg.

TABLE 5-11b. COST EFFECTIVENESS FOR LOWER-VOC SCENARIO 2(a)

	Model yard							
	Construction				Repair			
	Extra small	small	medium	large	Extra small	small	medium	large
Option 1								
Total emission reductions, Mg/yr	8.0	9.9	21.5	109.1	4.9	7.0	16.0	48.2
Costs, $/yr								
Additional coating(b)	25,980	49,995	90,411	199,774	27,985	42,157	57,818	163,518
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	31,338	62,964	106,965	240,973	33,343	55,126	74,372	204,717
Option 2								
Total emission reductions, Mg/yr	10.3	15.7	34.3	150.3	5.1	7.4	16.7	50.6
Costs, $/yr								
Additional coating(b)	26,810	52,115	95,152	215,025	28,054	42,297	58,079	164,422
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	32,168	65,084	111,706	256,224	33,412	55,266	74,633	205,621
Option 3								
Total emission reductions, Mg/yr	10.3	15.7	34.3	150.3	5.1	7.4	16.7	50.6
Costs, $/yr								
Additional coating(b)	26,810	52,115	95,152	215,025	28,054	42,297	58,079	164,422
Additional recordkeeping	12,116	27,338	38,983	88,273	12,116	27,338	38,983	88,273
TOTAL COSTS	38,926	79,453	134,135	303,298	40,170	69,635	97,062	252,695
Option 4								
Total emission reductions, Mg/yr	12.3	20.7	45.5	186.4	7.6	12.6	26.4	84.3
Costs, $/yr								
Additional coating(b)	19,702	33,953	54,543	84,400	16,692	19,033	14,782	14,721
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	25,060	46,922	71,097	125,599	22,050	32,002	31,336	55,920
Cost effectiveness, $/Mg								
Option 1	3,917	6,360	4,975	2,209	6,805	7,875	4,648	4,247
Option 2	3,123	4,145	3,257	1,705	6,551	7,468	4,469	4,064
Option 3	3,779	5,061	3,911	2,018	7,876	9,410	5,812	4,994
Option 4	2,037	2,267	1,563	674	2,901	2,540	1,187	663

(a)Example calculation for Option 1: For extra small yards, $31,338/yr / 8.0 Mg/yr = $3,917/Mg.

(b)Includes the annualized cost of in-line paint heaters.

TABLE 5-11c. COST EFFECTIVENESS FOR LOWER-VOC SCENARIO 3(a)

	Model yard							
	Construction				Repair			
	Extra small	small	medium	large	Extra small	small	medium	large
Option 1								
Total emission reductions, Mg/yr	3.2	7.0	15.5	54.0	3.6	7.0	13.3	45.1
Costs, $/yr								
Additional coating(b)	31,526	53,333	97,111	262,162	29,505	42,199	60,874	166,950
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	36,884	66,302	113,665	303,361	34,863	55,168	77,428	208,149
Option 2								
Total emission reductions, Mg/yr	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Costs, $/yr								
Additional coating(b)	32,135	55,320	101,585	274,922	29,569	42,339	61,127	167,844
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	37,493	68,289	118,139	316,121	34,927	55,308	77,681	209,043
Option 3								
Total emission reductions, Mg/yr	5.6	12.8	28.6	97.5	3.8	7.3	14.0	47.6
Costs, $/yr								
Additional coating(b)	32,135	55,320	101,585	274,922	29,569	42,339	61,127	167,844
Additional recordkeeping	12,116	27,338	38,983	88,273	12,116	27,338	38,983	88,273
TOTAL COSTS	44,251	82,658	140,568	363,195	41,685	69,677	100,110	256,117
Option 4								
Total emission reductions, Mg/yr	7.8	18.0	40.2	136.8	6.4	12.6	23.9	81.5
Costs, $/yr								
Additional coating(b)	24,706	36,965	60,588	140,689	18,103	19,072	17,620	17,909
Additional recordkeeping	5,358	12,969	16,554	41,199	5,358	12,969	16,554	41,199
TOTAL COSTS	30,064	49,934	77,142	181,888	23,461	32,041	34,174	59,108
Cost effectiveness, $/Mg								
Option 1	11,526	9,472	7,333	5,618	9,684	7,881	5,822	4,615
Option 2	6,695	5,335	4,131	3,242	9,191	7,576	5,549	4,392
Option 3	7,902	6,458	4,915	3,725	10,970	9,545	7,151	5,381
Option 4	3,854	2,774	1,919	1,330	3,666	2,543	1,430	725

(a)Example calculation for Option 1: For extra small yards, $36,884/yr / 3.2 Mg/yr = $11,526/Mg.

(b)Includes the annualized cost of in-line paint heaters.

under scenario 2 than under scenario 1 for options 1, 2, and 3.) This analysis indicates that in terms of cost effectiveness, the increased cost of paint heaters generally outweighs the improved emission reduction they achieve as one moves from scenario 1 to scenario 2.

It is anticipated that actual practice at shipyards will most closely resemble scenario 1. Many marine paints are used "as supplied". When the viscosity is to be reduced, thinning is the method of choice. However, to reduce the viscosity of coatings supplied with a VOC content at or near the limit, paint heaters will have to be used to avoid violating the limit, as in scenario 2. In rare cases, both thinner and heaters might be used, as in scenario 3.

Comparison of options. Tables 5-11a, 5-11b, and 5-11c show that across all three scenarios, the total costs above baseline increase progressively from option 1 through option 3, then decrease for option 4. Option 2 is slightly more costly than option 1 because the increase in paint cost per gallon slightly outweighs the savings from decreased paint and thinner use. The cost increase from option 2 to option 3 is larger because daily recordkeeping costs double, although paint costs remain constant. Costs decrease to their lowest level for option 4 because paint usage is reduced substantially while the cost model leaves the per-gallon cost of the paint unchanged from options 2 and 3. Under scenario 1, option 4 results in a net savings for repair yards of all sizes. Under scenarios 2 and 3, all yards show net costs for option 4.

The comparison of cost effectiveness for the options does not mirror the cost comparison. When the options based on maximum limits (options 1, 2, and 4) are compared, the cost model indicates cost effectiveness improves with the stringency of the limit. Thus, while the total cost for option 2 is greater than that for option 1, the cost increase is more than counterbalanced by the greater emission reduction achieved by option 2. Option 4 has lower costs and greater emission reduction than either option 1 or 2, resulting in the most favorable cost effectiveness by far.

The cost-effectiveness ranking of the option based on an average limit (option 3) differs between repair and construction yards. For repair yards, option 3 is the least cost-effective of all the options. For construction yards, option 3 falls between options 1 and 2 in cost effectiveness.

5.2 SPRAY BOOTH CONTROLS

Spray booths are used at some shipyards to apply coatings to parts before they are connected to the main part of the ship. Spray booths are used at both construction and repair yards. The use of add-on controls such as thermal incinerators for VOC emissions resulting from spray booth coating operations was evaluated. A conservative analysis was performed to develop preliminary cost estimates to be used to determine whether additional analysis was warranted. The assumptions and inputs used in evaluating add-on controls for spray booths are discussed in Section 5.2.1. The results of the analysis are presented in Section 5.2.2.

5.2.1 Spray Booth Analysis

Two aspects will be discussed in this section.

5.2.1.1 Methodology and Assumptions. Shipyards that fit the "extra small" classification criteria generally do not perform any indoor painting. The majority of the larger facilities do. At shipyards that paint indoors, some use spray booths; others do not. Rather, the spray area may be an entire building or an area of one. The spray booths used in shipyards vary significantly in size and number. The exhaust rate from individual booths can vary from about 0.7 to 62.3 cubic meters per second (m^3/s) (1,500 to 132,000 cubic feet per minute [ft^3/min]). The exhaust from entire buildings that function as spray areas can be more or less than that from booths, depending on the building and the spray operation.

The methodology used to estimate the costs of recuperative and regenerative thermal incinerators is that described in the

Office of Air Quality Planning and Standards (OAQPS) Cost Manual.[18] The Permissible Exposure Limit (PEL) for xylene is 100 parts per million (unless the operator uses a supplied air source). Xylene is the most prevalent paint solvent in the data base. Because manual coating operations are conducted inside booths, concentrations must remain at or below the PEL. Therefore, a maximum VOC concentration of 100 ppm was assumed in the analysis of spray booths. Due to the relatively low-concentration airstream entering the control device from the spray booths, a destruction efficiency of 95 percent was assumed for the thermal incinerators.[18] In costing add-on control devices, it was assumed that all the spray booths are operated at once, a worst-case assumption. Based on the survey responses, it was assumed that the booths operate 8 hours per day, 200 days per year. Other inputs used in the add-on control costing are shown in Table 5-12 and are described in more detail in Appendix C.

Generally, the spray booths now used in shipyards are not fully enclosed, so the capture efficiency of the exhaust system is expected to be less than 100 percent. To capture all of the emissions, the booth and the associated flashoff and drying areas would have to be enclosed. When an operator leaves the parts in the booth to cure, most of the emissions are released inside the booth. For this analysis, total capture was assumed, but the cost of the enclosure was not included, because of the lack of specific data. Therefore, the results presented provide a more favorable value of cost effectiveness ($/ton of VOC controlled), as the total cost of control is understated by the cost of the enclosure.

5.2.1.2 Total Spray Booth Flowrate. In developing the costs of using add-on controls to control VOC emissions from spray booth coating operations, it was assumed that one large unit would be used to control the exhaust from all the spray booths. In some shipyards, one large unit would be undesirable due to the distances between spray booths. Long lengths of ductwork would be needed between the booths and the control

TABLE 5-12. GENERAL DESIGN SPECIFICATIONS FOR ADD-ON CONTROLS

	Control device	
Specification	Thermal incineration--recuperative H.R[a]	Thermal incineration--regenerative H.R.[a]
Destruction efficiency, percent	95[b]	95[b]
Applicable range of flowrates, m^3/s (scfm)	<23.6 (<50,000)	>23.6 (>50,000)
Exhaust temperature, °C (°F)	25 (77)	25 (77)
Relative humidity of exhaust, percent	70	70
Operating temperature, °C (°F)	760 (1,400)	814 (1,500)
Pressure drop, centimeters of water (inches of water)	48 (19)	74 (29)
Equipment life, years	10	10
Heat recovery, percent	70	95
Incinerator warmup period, minutes	45	60[c]
Shifts operated per day	1	1
Annual operating hours	2,000	2,000

[a] H.R. = heat recovery.

[b] Destruction efficiency of 98 percent can be achieved if VOC concentration at inlet to control device is increased sufficiently (>300 ppm). A destruction efficiency of 98 percent can be achieved if air curtain booth spray booths are used.

[c] Unit is maintained at idle for 15 hours per day at 15 percent of the total flow.

device, and the large pressure drops associated with such long lengths of ductwork would make such a system impractical. In some instances, two smaller control units may be more practical, but the capital and operating costs would be higher. Thus, the assumption of one large unit will understate the costs and overstate the cost effectiveness.

Initially, the total spray booth flowrate to be controlled was calculated assuming all booths are used concurrently. Limits on the total number of booths operated concurrently and/or spray booth coating usage cutoffs (i.e., no control for booths that use less than some designated amount of coating) could reduce the maximum spray booth exhaust rate to be controlled. The analysis discussed here assumes that all booths operate at once and that all booths are exhausted to the control device.

Some spray booth information was provided from the surveys that were sent to shipyards as part of the CTG and NESHAP projects. This information was compiled and used to develop spray booth parameters for the add-on control analysis. It was determined that shipyards that fall into the "extra small" classification, whether construction or repair yards, generally do not have spray booths. Therefore, for purposes of the analysis, it was assumed that extra small model plants have no spray booths.

For each shipyard that provided complete information on all spray booths, the total spray booth flowrate, total coating usage, percentage of coatings used indoors, and the typical operating hours for each booth were compiled.[2] It was assumed that all coatings applied indoors were applied in spray booths. The estimated spray booth coating usage at each of the yards and the actual total spray booth exhaust at each yard (assuming all spray booths are used at once) were used in a linear regression analysis to develop an equation relating total spray booth coating usage and total spray booth exhaust.

Using the resulting regression equation, the flowrates for each of the shipyards with booths were estimated, and the estimated flowrates were compared to the actual flowrates. The agreement between the predicted flowrates and the actual flowrates was best for the larger yards. However, in all the model yard size ranges, the total flowrates from some yards were significantly below the predicted flowrates. Therefore, to represent such actual cases in the cost analysis, the minimum expected flowrates for all the model yards were determined by selecting the actual minimum flowrate for each model yard category. Only yards that supplied complete spray booth information were used in this selection process. Because the capital and operating costs of add-on controls increase with flowrate, the costs associated with these minimum flowrates represent the minimum costs that would be expected for the model yards. Likewise, the corresponding cost-effectiveness values are the minimum expected (i.e., the most favorable). The development of the regression equation and model yard spray booth flowrates is discussed further in Appendix C.

The total spray booth exhaust flowrates calculated for the model yards using the regression equation range from minimal up to 19.8 m^3/s (419,500 ft^3/min) for the large construction model yard. The minimum expected flowrates range up to 174 m^3/s (369,200 ft^3/min). The use of thermal incineration with recuperative heat recovery was evaluated for total spray booth exhausts less than or equal to 23.6 m^3/s (50,000 ft^3/min). Thermal incineration with regenerative heat recovery was evaluated for total spray booth exhaust flowrates greater than 23.6 m^3/s (50,000 ft^3/min).

Catalytic incineration and combined carbon adsorption/thermal incineration systems could also be considered but were not costed. In some instances, catalytic incineration and combined adsorption/thermal incineration may be less expensive, but the potential difference in cost is not expected to be significant.

5.2.2 Total VOC Emitted from Spray Booths

The amount of VOC emitted from the spray booths at each model yard was estimated based on the percentage of coatings and thinner applied indoors and corresponding average VOC contents. Detailed information concerning the type of coatings sprayed in the spray booths was not provided on the shipyard survey responses. Therefore, to calculate the VOC emissions from applying coatings in spray booths, the weighted average VOC content of all the coatings was used in conjunction with the VOC content of the thinner. Based on information contained in the shipyard survey responses, it was assumed that 10 percent of all coatings and thinner is sprayed in spray booths in each of the model yards except the large construction yard where 30 percent was used.[2]

The actual emission reduction associated with using add-on controls for spray booths could be lower or higher than that estimated in this analysis. Because 100 percent capture efficiency was assumed and the actual capture efficiency is expected to be less, the actual emission reduction may be less than estimated. On the other hand, actual emission reductions may be higher if cleaning solvents are used in the booth. Such miscellaneous cleaning could include gun, coating lines and pumps, and coating containers. The operating costs associated with the control device would increase very slightly if there is an increase in operating time, but the increase is not expected to be significant.

5.2.3 Spray Booth Add-on Control Analysis Results

The cost and associated emission reductions for using thermal incinerators to control VOC emissions from spray booth coating application operations were developed for each of the six model yards that use spray booths (the two "extra small" models do not have spray booths). Results of the model yard analysis, presented in Table 5-13, indicate the cost effectiveness of using add-on controls ranges from $44,700 to $338,000/Mg ($40,500 to $306,900/ton) of VOC reduced. Using the minimum expected

TABLE 5-13. SPRAY BOOTH ADD-ON CONTROL COSTS

	Construction				Repair			
	Extra small	Small	Medium	Large	Extra small	Small	Medium	Large
Average total paint usage, L/yr (gal/yr)	27,785 (7,340)	70,988 (18,753)	158,726 (41,931)	510,560 (134,876)	34,436 (9,097)	70,511 (18,627)	131,228 (34,667)	453,718 (119,860)
Average total indoor paint usage, L/yr (gal/yr)	0	7,100 (1,875)	15,900 (4,193)	153,000 (40,463)	0	7,050 (1,863)	13,100 (3,467)	45,400 (11,986)
Average total solvent use, L/yr (gal/yr)	14,415 (3,808)	10,845 (2,865)	43,532 (11,500)	162,132 (42,831)	10,224 (2,701)	1,893 (500)	20,562 (5,432)	23,091 (6,100)
Percent solvent used for thinning	50	40	20	50	20	3	20	20
Average total booth emissions, kg (lb)	0	3,160 (6,970)	6,990 (15,405)	80,800 (178,096)	0	2,780 (6,139)	5,520 (12,166)	18,300 (40,288)
95 percent emission reduction, Mg (tons)	0	2.7 (3)	6.3 (7)	77 (85)	0	2.7 (3)	5.4 (6)	17.2 (19)
Approximate total flowrate, m^3/s (ft^3/min)	0	46 (97,700)	557 (118,000)	198 (419,500)	0	46 (97,600)	52 (110,900)	86 (181,900)
Approximate thermal incinerator control cost, $/yr	0	894,900	1,056,000	3,438,000	0	894,900	999,700	1,562,200
Estimated cost effectiveness, $/Mg ($/ton)	N/A	298,000 (270,700)	155,000 (140,600)	44,700 (40,500)	N/A	338,000 (306,900)	191,000 (173,000)	89,700 (81,400)
Lowest expected flowrate, m^3/s (ft^3/min)	0	8.3 (17,600)	10.0 (21,200)	174 (369,200)	0	8.3 (17,600)	9.4 (20,000)	27.5 (58,200)
Approximate thermal incinerator control cost, $/yr	0	173,700	222,200	3,041,400	0	173,700	215,300	580,600
Estimated cost effectiveness, $/Mg ($/ton)	N/A	57,900 (52,500)	32,600 (29,600)	39,500 (35,800)	N/A	65,700 (59,600)	41,100 (37,300)	33,400 (30,300)

N/A = not applicable.

flowrates, the cost effectiveness ranges from $32,600 to $65,700/Mg ($29,600 to $59,600/ton). Because of the series of assumptions these values tend to be maximums. The cost would decrease if the booth airflows in the booths are reduced.

5.3 TANK PAINTING--USE OF ADD-ON CONTROLS[19-26]

Tanks are used to store fuel oil, jet fuel, ballast, and potable water. There can be as many as 1,000 tanks on an aircraft carrier; 500 may be on a single deck.[19] During construction, tank components may be painted before or after assembly. When a preassembled tank is painted it serves as a sort of natural enclosure. The same is true for voids on the ship that must be painted for corrosion protection. For purposes of this analysis, both tanks and voids are referred to as tanks.

The tank must be ventilated during painting to protect the worker and the final finish (dried overspray can settle on the finish). Because the tank acts as a natural enclosure, the VOC emissions resulting from the painting operation could conceivably be sent to an add-on control device. The feasibility and cost of using an add-on control to control tank painting operations was evaluated and is discussed in the following sections.

5.3.1 Feasibility of Add-On Controls for Tank Painting Operations

Add-on controls can be used to control VOC emissions resulting from tank painting operations. The enclosed nature of tanks makes efficient capture of the VOC emissions feasible with minimal or no modifications to the tank. These captured emissions can then be vented to an add-on control device for destruction. Although the use of add-on controls for tank painting operations is technically feasible, in some cases it may not be practical. During construction and repair operations, deck space is often limited because of the numerous activities occurring. At such times, it would be difficult to find space for an add-on control device on the deck. As discussed in Section 5.3.2, the maximum exhaust limitations of portable control devices would limit their usefulness for tank painting operations, regardless of space limitations. Therefore, if an add-on control device or multiple control devices were used to control VOC emissions from tank painting operations, they would probably have to be stationary units located on the ground. The size and configuration of each ship is different, and tanks are located all around a ship, so the location of the tanks relative to the control device would constantly vary. If tanks were vented to a control device located on the ground, long lengths of flexible ductwork would be needed. A significant pressure drop is associated with longer lengths of ductwork. It may be necessary to thread ductwork through a maze of passageways, and this may constrain the movement of equipment. Having flexible ductwork traveling from the tanks, through work areas, down to the control device might prove to be unsafe and would have to be evaluated.

The varying nature of the total volume of exhaust from all tank painting operations at any one time would have to be considered in designing and operating an add-on control system. Because the total airflow from all tank painting operations varies with the number and size of the tanks being painted, the airflow to be controlled could vary from about 0.47 m^3/s (1,000 ft^3/min) to several m^3/s (several hundred thousand . ft^3/min). Due to the changing capacity requirements, it might be advantageous to use multiple smaller-capacity add-on control units, rather than a single large unit. A combination of one large unit and several smaller ones may enable a shipyard to take advantage of the economy of scale offered by a larger unit while at the same time have the ability to control smaller airflows. A disadvantage of having multi add-on control units, is that the distribution of airflow among the units would change with time, as the tanks being painted changed, and this balance would have to be monitored. A certain warm-up period is required with add-on control units, and intermittent operation usually shortens the lifetime of the unit.

As stated above, using technology presently available to control VOC emissions from tank painting operations is feasible, though several challenges are present. There may be a market for some type of innovative package add-on control units that are suspended overhead, or canister units that can be taken below decks to the tank. The development of such technologies may make it easier and less expensive to use add-on controls for tank painting emissions control.

5.3.2 Assumptions and Inputs to the Analysis

A comprehensive discussion of the assumptions made and inputs that were developed as part of the tank analysis is provided in Appendix C.

Due to the variability in the number and size of tanks that may be painted at any time in a shipyard, add-on control costs were developed for a range of airflows rather than for individual model shipyards. Costs of using thermal incinerators with recuperative heat recovery to control airflows ranging from 0.9 to 37.7 m^3/s (2,000 to 80,000 ft^3/min) were estimated.

Controlled emissions were estimated using two methods. One estimate was based on the maximum <u>tank</u> VOC emissions calculated for the shipyards in the data base. For this estimate, the tank VOC emissions for each yard in the data base were calculated using the reported usage of tank coatings and corresponding VOC contents (as supplied) for the facility. Emissions from thinning the tank coatings 5 percent by volume were included. The maximum annual tank VOC emissions at any shipyard in the data base were estimated to be 18 Mg (20 tons) using this method.

Another estimate of maximum tank VOC emissions was made based on the maximum <u>total</u> VOC emissions from any of the shipyards in the data base. This second estimate of tank emissions was based on examination of the contribution of tank coating VOC emissions to total coating VOC emissions at yards in the data base. Based on the coating usage and classification data in the data base, the relative contribution of tank coatings to total coating VOC emissions (including thinner) was found to vary from less than 1 to 35 percent, with a mean of 9.8 percent. To obtain the second estimate of annual tank painting VOC emissions, which represents a maximum estimate, it was assumed that 9.8 percent of the total VOC emissions from coatings (including thinner) at the largest facility in the data base are from tank painting. The total tank coating-related VOC emissions for the largest facility were, thus, estimated to be 47 Mg (52 tons) annually, more than twice the first estimate.

5.3.3 Results of Tank Painting Add-On Control Analysis

The total cost and emission reductions for each of the scenarios evaluated are presented in Table 5-14. Although, the size and cost of a control device varies with the total air flowrate, the amount of VOC controlled were estimated in the two methods given above, independently of the flowrate. The cost effectiveness for each of the scenarios, calculated as the total cost divided by the total amount of VOC controlled, is also presented in Table 5-14.

Using the first emission reduction estimate (based on actual tank coating usage and VOC contents), the cost effectiveness varies from $5,000/Mg to $40,300/Mg ($4,500/ton to $36,300/ton). Using the maximum emission reduction estimate (calculated assuming 9.8 percent of the VOC emissions at the largest facility [in terms of total VOC emissions] are from tank painting), the cost effectiveness varies from $1,900/Mg to $15,500/Mg ($1,700/ton to $14,000/ton).

In reality, the amount of VOC controlled is dependent on the concentration of VOC's in the air stream and on the flowrate of the air stream flowing into the add-on control unit. However, in this analysis the estimates of VOC controlled are intended to represent average and maximum tank emissions expected at any shipyard. The actual amount of VOC controlled at any one facility would depend on the amount of tank painting done at the facility and the coatings used.

TABLE 5-14a. COST EFFECTIVENESS OF TANK ADD-ON CONTROL[a]
(Metric Units)

Flowrate, m^3/s	Annualized cost, $	Controlled emissions, Mg/yr[b]	Cost effectiveness, $/Mg[c]
0.9	90,800	18 (47)	5,000 (1,900)
2.4	124,700	18 (47)	6,900 (2,700)
4.7	170,700	18 (47)	9,500 (3,600)
9.4	280,400	18 (47)	15,600 (6,000)
18.9	435,800	18 (47)	24,200 (9,300)
28.3	582,900	18 (47)	32,400 (12,400)
37.7	726,200	18 (47)	40,300 (15,500)

TABLE 5-14b. COST EFFECTIVENESS OF TANK ADD-ON CONTROL[a]
(English Units)

Flowrate, scfm	Annualized cost, $	Controlled emissions, tons/yr[b]	Cost effectiveness, $/ton[c]
2,000	90,800	20 (52)	4,500 (1,700)
5,000	124,700	20 (52)	6,200 (2,400)
10,000	170,700	20 (52)	8,500 (3,300)
20,000	280,400	20 (52)	14,000 (5,400)
40,000	435,800	20 (52)	21,800 (8,400)
60,000	582,900	20 (52)	29,100 (11,200)
80,000	726,200	20 (52)	36,300 (14,000)

[a] Add-on control assumes a recuperative thermal incinerator with 70 percent heat recovery.

[b] Controlled emissions were calculated using two methods. The first number corresponds to the maximum calculated tank emissions using coating classification usage and composition data. The second number corresponds to maximum emission reduction estimate assuming 9.8 percent of maximum total VOC emissions are tank-related.

[c] Cost effectiveness numbers correspond to both sets of controlled emission rates that were calculated using two different methods.

5.4 COST OF CONTROL OPTIONS FOR PM-10 EMISSIONS FROM ABRASIVE BLASTING OPERATIONS

It was not possible to estimate how much it would cost to control PM-10. As discussed in Chapter 4.2.2, although a variety of actions are routinely taken by many plants to minimize particulate emissions, their effectiveness has not been quantified. Therefore, the cost effectiveness of PM-10 control options cannot be estimated at the present time.

5.5 CLEANING CONTROL COSTS

The cost associated with the use of accounting and management to track and control usage of cleaning solvents in a plant is discussed in the Alternative Control Techniques (ACT) for Industrial Cleaning Solvents[27]. The program for emission reductions from using solvents as a cleaning media described in the Industrial Cleaning Solvents ACT should be applicable to the shipbuilding and repair industry.

The cleaning needs at no two shipyards are exactly alike because of the different painting schedules and different paint used. Usually, the coating is stored in 18.9-L (5-gallon) or larger containers located on the floor of the dock. A pump transfers coating to the spray gun located on some type of elevated platform. In most yards, the length of the transfer line varies between about 15 and 46 m (50 and 150 ft). One yard was found to be using transfer lines 92 m (300 ft) long. The longer the transfer line the more solvent is needed to "flush" the line of paint residues. To clean the equipment after spraying, one end of the hose is placed in a small container and solvent is pumped through the hose and spray gun, and released back into the container. The spray gun head is often removed for cleaning, and the parts placed in a cleaning bucket. Cleaning solvent used only once can then be used to thin the coating. After more than one use, the spent solvent no longer can be used for thinning but rather must be disposed or purified. Some of the larger shipyards have on-site distillation units for purification; many shipyards send the spent cleaning solvent offsite for disposal or reclamation.[28]

5.6 ENVIRONMENTAL, ENERGY, AND OTHER IMPACTS

The environmental, energy, and other impacts presented here are the effects that using any of the VOC and PM-10 emission control options outlined in the previous sections of this chapter will have on air quality, water quality, hazardous wastes, energy usage, and other areas.

5.6.1 Environmental Impacts.

5.6.1.1 Air Quality Impacts. Emissions of VOC's are significantly reduced by implementing lower-VOC or add-on control options. Based on the information and assumptions presented in the earlier sections, switching from lower- to higher-solids coatings decreases the VOC content of the coatings and the total volume of coatings required. Therefore, emissions of VOC's are significantly decreased. If solvent thinner usage can be reduced or eliminated, the emissions of VOC's are further lowered.

The emission reductions achievable from incineration of spray booth emissions at large construction yards are significantly greater than those from other model yards simply because large construction yards use spray booths more frequently. The VOC emission reductions obtainable with incinerators are presumed to be 95 percent.

Auxiliary fuel is required for startup of thermal recuperative incinerator units as well as for maintaining a stable temperature. The auxiliary fuel used is assumed to be natural gas. The pollutant emissions resulting from natural gas use in incinerator units are nitrous oxides (NO_x), sulfur dioxides (SO_2), carbon monoxide (CO), residual particulate matter (PM), and various hydrocarbons. The emission factors for these pollutant emissions can vary depending upon the heat input required to destroy the waste gases, however, those used here are presented in Appendix C.[29] Table 5-15 summarizes the primary emissions that would result from a recuperative incinerator at each model plant. The majority of the emissions resulting from natural gas combustion is NO_x.

TABLE 5-15a. NATURAL GAS USE AND EMISSIONS FROM THERMAL RECUPERATIVE INCINERATION
FOR SPRAY BOOTH PAINTING OPERATIONS
(Metric Units)

Model yard[a]		Natural gas usage, KJ/yr	Emissions, kg/yr[b]				
No.	Description		PM	SO_2	NO_x	CO	Hydrocarbons
1	Construction, Large	2.16E+11	4.49E+02	5.39E+01	1.26E+04	3.14E+03	1.15E+03
3	Construction, Medium	6.09E+10	1.27E+02	1.52E+01	3.55E+03	8.87E+02	3.24E+02
5	Construction, Small	5.04E+10	1.05E+02	1.26E+01	2.93E+03	7.33E+02	2.68E+02
2	Repair, Large	9.38E+10	1.95E+02	2.34E+01	5.46E+03	1.37E+03	4.99E+02
4	Repair, Medium	5.72E+10	1.19E+02	1.43E+01	3.33E+03	8.33E+02	3.04E+02
6	Repair, Small	5.04E+10	1.05E+02	1.26E+01	2.93E+03	7.33E+02	2.68E+02

TABLE 5-15b. NATURAL GAS USE AND EMISSIONS FROM THERMAL RECUPERATIVE INCINERATION
FOR SPRAY BOOTH PAINTING OPERATIONS
(English Units)

Model yard[a]		Natural gas usage, Btu/yr	Emissions, lb/yr[b]				
No.	Description		PM	SO2	NOx	CO	Hydrocarbons
1	Construction, Large	2.05E+11	9.90E+02	1.19E+02	2.77E+04	6.93E+03	1.15E+03
3	Construction, Medium	5.78E+10	2.79E+02	3.35E+01	7.82E+03	1.95E+03	3.24E+02
5	Construction, Small	4.78E+10	2.31E+02	2.77E+01	6.47E+03	1.62E+03	2.68E+02
2	Repair, Large	8.90E+10	4.30E+02	5.16E+01	1.20E+04	3.01E+03	4.99E+02
4	Repair, Medium	5.43E+10	2.62E+02	3.15E+01	7.34E+03	1.84E+03	3.04E+02
6	Repair, Small	4.78E+10	2.31E+02	2.77E+01	6.47E+03	1.62E+03	2.68E+02

[a] Construction and repair extra small model yards were not evaluated because these yards were assumed to have no spray booths.
[b] Emissions were calculated based on emission factors for boilers in Reference 29.

Electrical energy is required to operate in-line coating heaters and the induced draft (ID) fans in the thermal incinerators. Secondary emissions of air pollutants (PM, SO_2, and NO_x) result from the generation of the electrical energy required to operate these devices. Secondary emissions were calculated assuming that the electrical power required to operate the devices is supplied by a bituminous coal-fired power plant that has a generator thermal efficiency of 38 percent.[30] The average heating value of bituminous coal is approximately 29,000 KJ/kg (12,600 Btu's per pound [Btu/lb]).[31] The emission factors used to estimate secondary pollutant emissions are presented in Appendix C.

Tables 5-16 and 5-17 summarize the secondary emissions associated with the electrical energy required to operate the in-line paint heaters and the incinerators. Secondary emissions caused by large construction yards are significantly greater than other model yards because of their larger waste gas flows vented to the incinerators. An increase in the electrical power required to operate the fans causes an increase in the secondary pollutant emissions that result from burning the fuel to generate the power.

5.6.1.2 Water Quality Impacts. No adverse water pollution impacts are expected from the use of any of the VOC control options.

5.6.1.3 Hazardous Waste. Liquid hazardous waste generated during shipyard painting operations consists primarily of spent solvent and coatings. The use of higher-solids coatings may require increased solvent usage for gun cleaning. However, because less of the lower-VOC coatings will be used (due to their higher-solids content), the overall amount of waste generated is expected to decrease for the same usage efficiency.

5.6.2 Energy Impacts

Fuel (natural gas) is needed for operation of the thermal incinerators. The resulting energy usage is presented in Table 5-15.

TABLE 5-16a. ELECTRICITY REQUIREMENTS AND SECONDARY EMISSIONS FROM USE OF IN-LINE PAINT HEATERS (Metric Units)

Model yard		Electricity, kW-hr/yr	Emissions, kg/yr[a]		
No.	Description		PM	SO_2	NO_x
1	Construction, Large	1.33E+06	1.63E+02	3.25E+03	3.25E+03
3	Construction, Medium	5.51E+05	6.77E+01	1.35E+03	1.35E+03
5	Construction, Small	3.43E+05	4.21E+01	8.39E+02	8.39E+02
7	Construction, Extra small	2.42E+05	2.97E+01	5.92E+02	5.92E+02
2	Repair, Large	1.19E+06	1.47E+02	2.92E+03	2.92E+03
4	Repair, Medium	4.71E+05	5.80E+01	1.15E+03	1.15E+03
6	Repair, Small	3.43E+05	4.21E+01	8.39E+02	8.39E+02
8	Repair, Extra small	2.55E+05	6.91E+01	6.24E+02	6.24E+02

TABLE 5-16b. ELECTRICITY REQUIREMENTS AND SECONDARY EMISSIONS FROM USE OF IN-LINE PAINT HEATERS (English Units)

Model yard		Electricity, Btu/yr	Emissions, lb/yr[a]		
No.	Description		PM	SO_2	NO_x
1	Construction, Large	4.54E+09	3.62E+02	7.17E+03	7.17E+03
3	Construction, Medium	1.88E+09	1.49E+02	2.97E+03	2.97E+03
5	Construction, Small	1.17E+09	9.29E+01	1.85E+03	1.85E+03
7	Construction, Extra small	8.26E+08	6.56E+01	1.31E+03	1.31E+03
2	Repair, Large	4.08E+09	3.24E+02	6.45E+03	6.45E+03
4	Repair, Medium	1.61E+09	1.28E+02	2.54E+03	2.54E+03
6	Repair, Small	1.17E+09	9.29E+01	1.85E+03	1.85E+03
8	Repair, Extra small	8.71E+08	6.91E+01	1.38E+03	1.38E+03

[a] Secondary emissions were calculated based on emission factors for bituminous coal combustion in Reference 31.

TABLE 5-17a. ELECTRICITY REQUIREMENTS AND SECONDARY EMISSIONS FROM THERMAL INCINERATION FOR SPRAY BOOTH PAINTING OPERATIONS (Metric Units)

Model yard[a]		Electricity, kW hr/yr	Emissions, kg/yr[b]		
No.	Description		PM	SO_2	NO_x
1	Construction, Large	5.36E+06	6.59E+02	1.31E+04	1.31E+04
3	Construction, Medium	1.51E+06	1.85E+02	3.68E+03	3.68E+03
5	Construction, Small	1.25E+06	1.53E+02	3.05E+03	3.05E+03
2	Repair, Large	2.32E+06	2.85E+02	5.68E+03	5.68E+03
4	Repair, Medium	1.41E+06	1.74E+02	3.46E+03	3.46E+03
6	Repair, Small	1.25E+06	1.53E+02	3.05E+03	3.05E+03

TABLE 5-17b. ELECTRICITY REQUIREMENTS AND SECONDARY EMISSIONS FROM THERMAL INCINERATION FOR SPRAY BOOTH PAINTING OPERATIONS (English Units)

Model yard[a]		Electricity, Btu/yr	Emissions, lb/yr[b]		
No.	Description		PM	SO_2	NO_x
1	Construction, Large	1.83E+10	1.45E+03	2.89E+04	2.89E+04
3	Construction, Medium	5.14E+09	4.08E+02	8.12E+03	8.12E+03
5	Construction, Small	4.26E+09	3.38E+02	6.73E+03	6.73E+03
2	Repair, Large	7.93E+09	6.29E+02	1.25E+04	1.25E+04
4	Repair, Medium	4.83E+09	3.83E+02	7.63E+03	7.63E+03
6	Repair, Small	4.26E+09	3.38E+02	6.73E+03	6.73E+03

[a] Construction and repair extra small model yards were not evaluated because these yards were assumed to have no spray booths.

[b] Secondary emissions were calculated based on emission factors for bituminous coal combustion in Reference 31.

The electrical requirements of in-line heaters and thermal incinerators are presented in Tables 5-16 and 5-17, respectively. The necessary calculations for this section are described in Appendix C.

5.6.3 Other Environmental Impacts

Other environmental impacts include noise impacts from implementing any of the control options for all model yards. In general, thermal incinerators require additional equipment (larger ID fans to overcome pressure drops) that will increase noise levels. However, theincrease is believed insignificant.

5.7 REFERENCES FOR CHAPTER 5

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32. Memorandum. Reeves, D., MRI, to Project File. Industry meeting minutes. September 15, 1993.

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6.0 Factors to Consider in Developing BEST AVAILABLE CONTROL MEASURES (BACM)

This Chapter presents information on factors that regulatory agencies should consider to select the best available control measures (BACM) for VOC emissions from painting activities in the shipbuilding and ship repair industry. Alternative technologies (and options for one) were discussed in Chapter 3.

Findings regarding particulate emissions from abrasive blasting are presented in Chapters 2 through 4. Because test data was not available to us at this time our suggestions deal only with changes in "manufacturing practices" and "work practices.".

To control emissions from cleaning solvents, States should consider the alternatives described in the "Alternative Control Techniques (ACT) for Industrial Cleaning Solvents," EPA number EPA-453/R-94-015, dated February 1994.

The statutory authority and goals for establishment of BACM is discussed in Section 6.1 for the benefit of the State regulators. In developing BACM for this industry a State agency may select from control techniques stated in this report or may transfer technology from other industries. Authorities may also develop BACM on a case-by-case basis, considering the economic and technological circumstances of the individual source. The final rules must, however, be enforceable; include provisions which allow determination of compliance.

In Section 6.6, factors to be considered for each individual source are discussed. Information is provided related to emission testing, equipment under-development, monitoring and reporting/record keeping.

6.1 BACKGROUND

The Clean Air Act, as amended in 1990, requires that control techniques to control VOCs and PM_{10} from the shipbuilding and ship repair industry be based on BACM. This mandate represents a stricter standard than has been applied to regulate emissions of VOCs and particulates in non attainment areas: previous standards for protecting the ambient air quality have been based on reasonably available control technology (RACT).

6.2 DEFINITIONS

The Shipbuilding and Ship repair rule should accurately describe the sources that will be affected and use terms that are clearly defined to describe the method of control. The terms and definition described in this document may need to be clarified when used in the context of a rule. A short list of helpful definitions is given in Appendix A.

A large source of air emissions in Shipyards are organics from marine coatings. Chapter 2 discusses types of marine paints, resins and equipment and application processes used. Different types of paints are discussed and defined under Section 2.2.1.

Table 2-9 lists a number of paint categories. The categories correspond to those in that appear in the California coatings rules (effective in 1992) in addition to four categories that were added based on Department of Navy (NAVSEA) recommendations. The definitions for the 23 paint categories are given in Chapter 2. However, a State may elect to expand on the definitions as this report has done for nuclear coatings.

6.3 APPLICABILITY

As outlined in Chapter 2.0, the shipbuilding and ship repair industry consists of establishments that build and repair ships (Fiber glass reinforced ship manufacturing processes are excluded). A definition for a ship is also provided in Chapter 2.0 to define the shipyards that would be subject to a rule. Emissions from painting of drilling and offshore production platforms (which are a part of SIC Code 3731) were not included in the Agency's investigation. The coatings category "navigational aids" was included in the rule because buoys and other waterway markers are exposed to the same weathering conditions (e.g., corrosion) as a ship. The implementing agency, may, of course, elect to include in its rule other paint categories that it deems appropriate.

6.4 FORMAT OF THE STANDARD

The BACM regulations for this source category may be based on one or more of the following formats.

1. Use of VOC limits
2. An equipment standard; and
3. A percent reduction level.

6.4.1 Use of VOC Limits

The EPA has evaluated the VOC control achievable by limiting the maximum allowable VOC content of individual coatings and another based on the weighted average VOC. The advantages and disadvantages of one option relative to another are discussed in Chapter 5. Table 1-1 presents a maximum, as-applied VOC of various paint categories.

6.4.2 Equipment Standard

Air and airless spray equipment are commonly used in this industry. The possibility of specifying special spray equipment such as high volume low-pressure or "HVLP" was investigated to gain the benefit of less paint waste (and lower VOC emissions) due to the softer delivery of paint to the substrate. Although it seems clear that such equipment is desirable, some shipyards allege that low pressure systems are unable to accommodate some of the higher solids coatings used by the industry.

6.4.3 Percent Reduction

Standards in this form are commonly used when the control system is anticipated to be an "add-on" device such as an incinerator or carbon adsorber. There are, however, no commercially available technologies for enclosing outside areas of a ship (a critical prerequisite for add-on devices) although a number of US companies are working on different enclosure designs. Several technologies under development are reviewed in Chapter 3. Efficient enclosures are desirable for many reasons. They would help in controlling PM_{10} emissions; pollution due to storm water runoff could be almost eliminated. They would make it possible for a shipyard to addon control equipment such as catalytic incinerators and carbon adsorption systems to reduce VOC emissions.

Add-on controls may be applicable for storage tanks in ships and when painting operations within buildings in a shipyard.

6.5 EMISSION REDUCTION AND COST

The emission reduction and cost impacts associated with several options are summarized in Tables 5.11. For compliance scenario 1 (see Section 5.1.2), which is expected to most closely approximate actual practice at shipyards, the costs for recordkeeping and reporting as estimated affect significantly total cost and cost effectiveness of an option.

6.6 ADDITIONAL FACTORS TO BE CONSIDERED.

The cost to control emissions from several units was determined based on painting operations believed to be typical of most shipyards. There may, however, be situations where other emission limitations or recordkeeping provisions are more appropriate. Some potential cases are discussed below.

As presented in Table 5-13, the estimated cost effectiveness of add-on controls for spray booths at the models used to represent a variety of shipyards is very expensive. Where facilities operate paint spray booths continuously with relatively high paint use rates of high VOC coatings, the cost effectiveness of add-on controls may be much more favorable. For example, at one shipyard, an automated system for applying preconstruction primer to steel plate is being retrofitted with an abatement system. A State may choose to analyze spray booth usage patterns on a case-by-case basis to determine whether add-on controls are cost-effective. Part of the evaluation should be to determine the minimum flow of exhaust air from the booth during painting based on VOC emissions and Occupational Safety and Health Administration (OSHA) requirements. Cost effectiveness of control is inversely related to exhaust air flow from the booth.

All ships have fuel and ballast tanks. Some have other types of tankage. The number, size, location, and type of tanks to be painted may vary widely from day to day. Because the interior of a tank is essentially a total enclosure, control of tank painting emissions may be cost-effective if sufficient tanks (and similarly enclosed substrates) are painted so that there is a near continuous source of VOC feed to the control device.

Because viscosity is inversely related to temperature, at some point paints must be thinned (or heated) to reduce viscosity so that the spray guns will atomize the coating.

It has been impossible to determine at what temperature such thinning must be initiated because traditionally, solvent has been added to shipyard paints even under circumstances where the coating manufacturer often instructs that no solvent addition is necessary or recommended.

Since the only acceptable and legitimate purpose for allowing paint to be thinned is to assure the resulting viscosity permits it to be applied by spray, a State might use that relationship to establish the maximum allowable dilution rate. The shipyard might be required to determine the temperature at which their spray systems are no longer capable of atomizing the coating and then limit the requisite solvent additions to that necessary to achieve the requisite viscosity at existing ambient temperatures.

Because data on emissions from abrasive blasting for cleaning metal surfaces was not available and tests conducted by the Agency did little to enlighten, it was not possible to evaluate achievable reductions and cost effectiveness of options to reduce that source of PM_{10} emissions. Suggestions on work practices that reduce overall emissions are likely to also control PM10 emissions.

6.7 TEST PROCEDURES

EPA Method 24 [2] is the recommended procedure for measuring VOC from paints and coatings. The Administrator may approve a request for an "equivalent" method if it yields equivalent results.

6.8 REPORTING AND RECORD KEEPING

The recordkeeping assumed for this analysis was based on daily records of paint and thinner usage that would allow the as-applied VOC content of the paints to be calculated for each day. If a shipyard does not thin its paints before application, a State may allow it to certify the VOC of paints "as supplied" (with VOC contents certified by the paint supplier) and that no thinning solvent was added.

A similar approach might be considered for yards that use only paints that meet the VOC limit, even when thinned to the maximum level recommended by the paint supplier. An appropriate certification procedure is described in reference 3.

The VOC content of a coating should not be estimated from solvent composition data provided in a material safety data sheet (MSDS) nor should it be based on the VOC value given in product data sheet (PDS). Often that information is presented in very general terms (the MSDS presents species concentrations in terms of ranges rather than specific terms) and the VOC values on product data sheets are commonly (and erroneously) presented in terms of the paint solvent in the formulation, omitting the contribution of volatile organic by-products of the cure reaction (see Chapter 2). For determining compliance, specific paint data should be used. As detailed in the Agency's publication "procedure for Certifying Quality of Volatile Organic Compound Emitted by Paint Ink and Other Coatings" [3]. That report provides step-by-step instructions for manufacturers and users of coatings to provide information on VOC emitted by a coating.

6.9 REFERENCES FOR CHAPTER 6.0

1. Alternative Control Techniques Document--Industrial Cleaning Solvents; US EPA, RTP, NC 27711; EPA-453/R-94-015, February 1994; NTIS: PB94-156791.

2. EPA Method 24 (40 CFR Part 60 Appendix A).

3. Procedures for Certifying Quantity of Volatile Organic Compounds Emitted by Paint, Ink and Other Coatings," (Revised June 1986); US EPA, NC, 27711; EPA-450/3-84-019.

APPENDIX A

SPECIAL DEFINITIONS

SPECIAL DEFINITIONS

- <u>Cleaning Practice</u>
  A repeated or customary action that is specific to an industry. An example is nightly maintenance of a spray booth or maintaining solvent waste containers closed.[1]

- <u>Nuclear coatings</u>
  These are protective coatings used to seal porous surfaces such as steel (or concrete) that otherwise would be subject to intrusion by **radioactive materials.** These coatings must be **resistant** to **long-term cumulative radiation exposure, relatively easy** to decontaminate and resistant to various chemicals used to which the coatings are likely to be exposed.[2] (General protective requirements are outlined by the Department of Energy (U. S. Atomic Energy Commission) <u>Regulatory Guide 1.54.)</u>

  Several terms in the above definition are defined for specifity.

  <u>Radioactive Materials (isotopes)</u>: Contamination of a surface (or substrate) can occur via air-borne, water-borne materials or smearable means (e.g., during a spill or leak).
  <u>Resistant to Chemicals</u>: This is evaluated using ASTM 3912-80 (except for potassium permanganate) or an equivalent test method .
  <u>Decontamination</u>: Protective coatings should be decontaminable per ASTM D4256-83 or an equivalent method
  <u>Radiation Tolerance</u>: This is be evaluated using ASTM D4082-83 or an equivalent method.

- <u>Product substitution</u>
  Replacement of any product or raw material intended for an intermediate or final use with another. This substitution is a source reduction activity if either the VOC emissions or the quantity of waste generated is reduced.[1]

- <u>Work Practice</u>
  This term is reserved for specific human activities within industry that lead to a reduction in VOC emissions (or waste). The activities include increased operator training and management directives. It does not include the use of specialized equipment, such as (cleaning) solvent dispensers.[1] Cost items under this heading involve training personnel on proper procedures for diluting coatings, keeping coating records, or handling solvent containing materials.

A.2 REFERENCES FOR APPENDIX A

1. Alternative Control Techniques Document--Industrial Cleaning Solvents. US EPA, OAQPS (MD-13), RTP, 27711, EPA-453/R-94-015 (February 1994). NTIS PB94-156791.

2. M. Serageldin., EPA, to Project File. Definition of Nuclear Coatings. Adapted from Carboline Company, Nuclear Binder. December 1993.

APPENDIX B.
EMISSION ESTIMATES

APPENDIX B.
EMISSION ESTIMATES

Appendix B is a compilation of the background information and methodology used to develop Chapter 4, Model Shipyards and Emission Estimates. Section B.1 presents information used to develop the model yards, and Section B.2 presents the methods and sample calculations for estimating emissions.

B.1 MODEL YARD DEVELOPMENT

Model yard development was based primarily on coatings information gathered from responses to 37 questionnaires EPA sent to industry and the Department of Navy. The questionnaires solicited information on emissions of both VOC and HAP's.[1] Of these 37, 3 were not used because the yards were not considered full-service. Another yard was deleted due to the lack of coatings information provided. Coating manufacturer surveys and site visits supplemented the information received from the shipyards.[2,3] A coatings data base was formed from the shipyard information. The information gathered was analyzed to determine the types of coatings used in the ship industry, coating usage trends, and VOC content correlations.

Based on the survey information, three major coating categories account for 90 percent of the coatings used by the industry. These are antifoulants, inorganic zincs, and general-use coatings. The other 10 percent is attributable to a variety of other coatings used for special purposes. Information on the three major-use coating categories was used to develop model yards.

Due to the diverse nature of the industry, three different options were evaluated for developing models to represent the variety of yards. These options were: (1) the type of vessel coated--military or commercial, (2) the type of operation--ship construction or ship repair, and (3) the size of the shipyard. The results of analyzing each option are as follows.

Option 1: Military Versus Commercial. Military vessels are highly sophisticated sea vessels and therefore are very expensive to construct. Military vessels need to be in a constant state of mission readiness between drydockings. Coatings systems on military vessels are required to perform a variety of functions including corrosion protection, camouflage, resistance to wear from the landings and take-offs of aircraft on landing decks, resistance to heat damage from surfaces that are exposed to fire, and ability to withstand the severe chemical exposure used to decontaminate chemical warfare agents. Commercial vessels are considerably less sophisticated and less costly to construct. Frequent drydockings are required for commercial vessels. Therefore, the durability of coating systems between drydocking should be of less concern for commercial ships.

The yards within the data base were classified as either military or commercial yards, depending on the primary source of their revenue (military or commercial jobs). The coatings information gathered from the Section 114 responses indicates that there are no distinct differences in coating usage trends or VOC contents between predominantly commercial and predominantly military yards. Because the majority of the information gathered pertained to military yards, however, any differences between military and commercial yards may have been masked.

Option 2: Construction Versus Repair Yards. Yards within the data base were classified as either construction or repair yards depending on their major source of revenue. The coatings information in the data base indicates that there are no distinct differences in the VOC contents of coatings used at construction yards and repair yards. Both use the same coatings, just not in the same quantities. There are, however, significant differences in relative coating usages for construction and repair yards. Construction yards tend to use significantly more inorganic zincs and general use coatings as a percentage of total coatings applied than repair yards, while repair yards tend to use proportionally more antifoulants.

Option 3: Size Classification. The shipyards in the data base were segregated based on total coating usage to determine if any significant differences exist between small, medium, and large yards. The data base reveals no major differences in the types of coatings or relative coating usages attributable to size. Consequently, the VOC contents of the three major-use coatings are presumed essentially the same regardless of yard size.

B.1.1 Model Yard Selection

Because major differences were found in the relative usage of the three major paints used at construction and repair yards, the type of work was considered the most significant characteristic for segregating yards into models that could be used to characterize the "shipbuilding" and "ship repair" industry.

B.1.1.1 Construction Versus Repair Classification. For the purpose of placing data from the shipyards into different model yard categories, yards were classified based on where 70 percent of their total revenue was from, construction or repair work. Two yards in the data base could not be assigned on this basis and their data were not used.

B.1.1.2 Size Determination. Eight model yards (four construction and four repair) were developed from the information derived from the coatings data base. These eight model yards represent four model yard sizes (extra small, small, medium, and large) that correspond to the emission rate used to define a "major source" in extreme, severe, serious, and moderate nonattainment areas, respectively. Therefore, "extra small" model yards are those that emit less than 22,680 kilograms per year (kg/yr) (25 tons/yr) of VOC's. "Small" model yards emit between 22,680 kg (25 tons) and less than 45,360 kg/yr (50 tons/yr) of VOC's. "Medium" model yards emit between 45,360 kg (50 tons) and less than 90,720 kg/yr (100 tons/yr). of VOC's, and "large" model yards emit 90,720 kg/yr (100 tons/yr) or more.

B.1.2 Model Yard Parameters

Table 4-2 summarizes the average total coating, solvent, and abrasive media usages for each model yard class. They are the averages reported by the shipyards that were assigned to that model. For example, three yards in the data base had emissions consistent with those of the large repair model yard class. To obtain the average coating usage for the large repair model yard class, the total coating usages reported by the three yards were summed and divided by three. This calculation, with all usage volumes on a less water less 'exempt' solvent basis, is as follows:

Example: Average Total Coating Usage for the Large Repair Model Yard Class

	Yard No.	Coating usage reported, 1,000 L/yr (1,000 gal/yr)
	7	515.6 (136.2)
	15	421.3 (111.3)
	37	424.0 (112.0)
Total:	3 shipyards	1,361 liters (359.5 gallons)

$$\left(\frac{359.5 \text{ x } 10^3 \text{ gal/ yr}}{3 \text{ yards}} = 119.8 \text{ x } 10^3 \text{ gal/yr}\right)$$

Similar methodologies were used to obtain all other model yard parameters presented in Table 4-2.

B.1.3 Relative Usages

The relative coating usages determined for both construction and repair shipyards are presented in Table 4-3. The relative usage for each model yard was determined by dividing the usage of each coating category by the total of all coating used. Relative usages for repair model yards were calculated in the same manner. The following example uses all volumes on a less water less VOC 'exempt' compounds basis:

Example:

1. Total antifoulant usage for construction model yards = 1.31×10^5 L (34,535 gal)
2. Total coating usage for construction model yards = 3.27×10^5 L (862,611 gal)

$$\text{calculation: } \frac{1.31 \times 10^5 \text{ L}}{3.27 \times 10^5 \text{ L}} = 4 \text{ percent}$$

$$\left(\frac{34{,}535 \text{ gal}}{862{,}611 \text{ gal}} = 4 \text{ percent} \right)$$

Thus, antifoulant comprises 4 percent of the total coating usage at construction model yards.

B.1.4 Average VOC Content Determination

The VOC emissions from coatings were calculated based on the amount of organic solvent in the coatings. The compound 1, 1, 1 trichloroethane was the only VOC 'exempt' solvent in the paint data submitted by the industry. The total amount of 1, 1, 1 trichloroethane containing paint was insignificant, less than 50 gallons.

Table 4-4 gives the weighted (normalized) average VOC content, i.e., the average VOC content weighted by volume used, for each of the three major-use coatings used by the industry and the solvent category. These averages were calculated from all reported coatings and solvents. They were not evaluated for construction and repair yards separately because both were found to use the same types of coatings and solvents; just not in the same relative quantities. The VOC contents of individual coatings were provided by the shipyards; this information was supplemented by data gathered from manufacturers of marine coatings. The weighted averages were calculated as follows. First, the usage and corresponding VOC contents of the coatings within a category were multiplied to obtain the total VOC represented by the coatings. The sum total VOC of the coatings within that category was then divided by the sum total of the usages associated with the coating category to obtain the weighted average VOC content. The overall VOC content for the solvent category was calculated in the same manner as that of the coating categories. The following example uses all volumes on a less water and less VOC 'exempt' compounds basis:

Example:

1. Total antifoulant VOC from all antifoulants in data base = 2.6×10^8 grams (g) (5.8×10^5 pounds [lb])
2. Total volume associated with antifoulant VOC = 6.8×10^5 L (1.8×10^5 gal)

Average VOC content calculation for antifoulant:

B.2 EMISSION ESTIMATES

Table 4-5 gives a breakdown of the VOC emissions by category for each model shipyard. The VOC emissions for each coating category is the product of the average total coating use, the relative use (Table 4-3), and the weighted average VOC content (Table 4-4). For example, from Table 4-5, the VOC emissions in metric units) associated with specialty antifoulant usage at extra-small construction model yards were calculated to be:

$$\frac{(27{,}785 \text{ L/yr}) \times .04 \times (387 \text{ g/L})}{1{,}000 \text{ g/kg}} = 400 \text{ kg/yr (rounded)}$$

where:

27,785 L/yr = average total annual coating usage for extra small construction model yards;

0.04 = relative antifoulant usage at construction yards;

387 g/L = weighted average VOC content calculated for all antifoulants; and

1,000 g/kg = conversion factor for g to kg.

The total amount of solvent used for each of the model yards including the breakdown of usage between thinning and cleaning, was based on information obtained from the Section 114 responses (the data base). In developing these emission estimates, the VOC content associated with all cleaning and thinning solvents is assumed to be 839 g/L (7.0 lb/gal). The VOC emissions estimated for the thinning solvent category are the product of the average total solvent usages, the percent solvent used for thinning, and the weighted average VOC content for all solvents. For example, the VOC emissions in metric units resulting from thinner usage estimated for extra-small construction model yards are calculated to be:

$$\frac{14{,}415 \text{ L/yr} \times .50 \times 839 \text{ g/L}}{1{,}000 \text{ g/kg}} = 6{,}000 \text{ kg/yr (rounded)}$$

where:

14,415 L/yr = average total annual solvent usage for extra small construction model yards;

0.50 = percent solvent used at extra small model yards for thinning;

839 g/L = assumed VOC content for all solvents; and

1,000 g/kg = conversion factor for g to kg.

Emissions from cleaning were assumed to be at least 35 percent by volume of all cleaning solvents used. Therefore, as an example, cleaning solvent VOC emissions (metric units) in Table 4-5 for extra small construction model yards were calculated to be:

$$\frac{0.35 \times 14{,}415 \text{ L/yr} \times 0.50 \times 839 \text{ g/L}}{1{,}000 \text{ g/kg}} = 2{,}100 \text{ kg/yr (rounded)}$$

where:

0.35 = assumed emission rate from cleaning solvent usage;
14,415 L/yr = average total annual solvent usage for extra small construction model yards;
0.50 = percent solvent used for cleaning at extra small construction model yards;
839 g/L = assumed VOC content for all solvents;
1,000 g/kg = conversion factor for g to kg.

The VOC emissions associated with the other coating/solvent categories for extra small construction model yards were estimated. The overall VOC emissions from extra small construction model yards are the total for all the categories under that model yard class. Similar calculations provided parameters for the other seven model shipyards.

No data were available to estimate PM-10 emissions associated with abrasive blasting operations at model yards.

REFERENCES FOR APPENDIX B

1. Memorandum from deOlloqui, V., Midwest Research Institute (MRI), to Project File. Facilities in the Shipbuilding and Ship Repair Data Base. November 11, 1992.

2. Memorandum from deOlloqui, V., MRI, to Project File. List of Coating Manufacturers Surveyed. November 16, 1992.

3. Memorandum from Williamson, M., MRI, to Project File. List of Shipyard Site Visits. March 18, 1993.

APPENDIX C.

COST ANALYSIS

APPENDIX C.

COST ANALYSIS

Appendix C is a compilation of the background information and methodology used to develop Chapter 5, Costs and Environmental and Energy Impacts. The development of coating parameters is discussed in Section C.1, and calculations of emission reductions and costs associated with the use of lower-VOC coatings are described in Section C.2. The development of inputs for the spray booth analysis is described in Section C.3, and the tank analysis is described in Section C.4. The estimation of energy and environmental impacts is discussed in Section C.5.

C.1 COATING PARAMETER DEVELOPMENT

The Section 114 responses received from the shipyards and coating manufacturers were the primary sources of coating information.[1,2] Based on this information, three primary major-use coating categories were identified: "general use", inorganic zinc, and antifoulant coatings. The last two categories each account for at about 10 percent of total coating use in the industry, and all three account for close to 90 percent of the total coatings in the project's data base. A variety of specialty coating categories account for the balance of coatings used in the industry. For simplicity, and because of resource limitations, the analysis was limited to the major-use coating categories.

The general use coating category was examined initially by breaking it down by resin type. Alkyd and epoxy resin coatings were broken out. However, the coating characteristics and intended use of coatings within a single resin type, such as epoxy, vary considerably. Due to these difficulties, these coatings were later combined into a single category referred to as general use coatings. The general use coating parameters were calculated using alkyd and epoxy information contained in the data base. The development of the coating parameters for alkyds and epoxies individually is discussed in this appendix, as well as that of the combined general use category.

C.1.1 Solids (Nonvolatile matter) Content

As discussed in Section 5.1.2, the solids contents of the coatings were generally estimated assuming that a coating is comprised of solids and volatile organic compounds (VOC). That is, the solids content of a coating was calculated by assuming that everything in the coating that is not VOC is solids. An example calculation used to aid in comparing paint costs is:

Solids (gallon [gal]) + VOC (gal) = coating volume (gal)

Assuming 1 gal of coating:

Solids (gal) = (1 gal coating) - VOC (gal)

Divide by total gallons of coating

$$\frac{\text{Solids (gal)}}{\text{1 gal coating}} = 1 - \frac{\text{VOC (gal)}}{\text{gal coating}}$$

$$\text{Solids (\% by volume)} = \left[1 - \frac{\text{VOC (gal)}}{\text{gal coating}}\right] \times 100$$

$$\text{Solids (\% by volume)} = \left[1 - \frac{\text{VOC content of coating (lb VOC/gal coating)}}{\text{density of solvent (lb VOC/gal VOC)}}\right] \times 100$$

Assuming the density of the VOC is 7.0 lb/gal, and that the VOC content of an example coating is 4.0 lb VOC/gal.

$$\text{Solids (\% volume)} = \left[1 - \frac{4.0\ \text{lb VOC}}{\text{gal coating}} \times \frac{1\ \text{gal VOC}}{7.0\ \text{lb VOC}}\right] \times 100$$

$$\text{Solids (\% volume)} = [1 - .57] \times 100 = 43\ \text{percent}$$

The solids content of several high-usage alkyds and inorganic zincs were not estimated in the manner described above; manufacturer's data on solid content was used.

C.1.2 Other Coating Parameters

The weighted average VOC content and price of the three primary coating categories were calculated for the baseline and lower-VOC options (see Section 5.1.1). The VOC content of all the coatings in the shipyard data base was provided by the shipyards and/or the coating suppliers.[1,2] The price of most but not all of the coatings was also provided by the shipyards. The weighted average VOC content at baseline for each of the primary coating categories was calculated by multiplying the VOC content of each coating by its corresponding usage (gallons adjusted for any water or 'exempt' compounds), summing this product, and dividing by the total coating usage. To calculate the weighted average VOC content for the lower-VOC options, coatings with a VOC content exceeding the VOC limits (Table 1.1) were each assigned values corresponding to the appropriate paint category limit. VOC content of coatings that were already at or below the limits were not modified. The weighted average VOC contents for the lower-VOC scenarios were then calculated in the same manner as described for the baseline using actual usage values for each coating. This resulted in one average value.

The weighted average price of the baseline and lower-VOC coatings were calculated in a similar manner. However, because prices were not provided for all coatings, those coatings without prices were first eliminated from the data base (only for the calculation of weighted average price). For the lower-VOC options, the weighted average price of existing coatings with VOC contents equal to or less than the limit was calculated, and this price was used for all lower-VOC coatings. Using these revised prices, a weighted average lower-VOC price was calculated for each of the primary coating categories.

C.1.3 Solvent Usage

Solvent is used in shipyards for two primary uses--cleaning and thinning. For the lower-VOC cost analysis, only the portion of total solvent that is used for thinning was necessary. The amount of thinning solvent used at each of the model yards was calculated based on information in the shipyard data base. Based on total coating usage and the type of work performed (construction versus repair), each of the shipyards in the data base was put into a model yard category. The total solvent usage and thinning solvent usage were calculated for each of the plants, and average usages were developed for each of the model plant categories.

C.2 LOWER-VOC EMISSION REDUCTIONS AND COSTS

Based on the coating parameters corresponding to the baseline and lower-VOC levels as discussed in Section C.1, the VOC emission reduction and costs associated with the use of lower-VOC coatings were estimated for each of the model yards. In addition, the cost of recordkeeping and reporting associated with rules based on lower-VOC coatings was estimated. Section C.2.1 discusses emission reduction estimates, Section C.2.2 discusses costs associated with lower-VOC coatings, and Section C.2.3 discusses recordkeeping and reporting costs.

C.2.1 Emissions Reductions

As presented in Section 5.1.2, three lower-VOC scenarios were considered. Scenario 1 assumes that thinner solvent usage, as a percentage of total coating usage, is constant, and that in-line heaters are not required. Scenario 2 uses in-line paint heaters in lieu of thinning solvent. Scenario 3 uses paint heaters in conjunction with constant thinning solvent usage.

The reduction in VOC emissions is attributable to two factors: (1) reduced total coating usage (gallons) due to increased solids contents and (2) corresponding decreased thinner usage. The only differences between Scenarios 1, 2, and 3 involve in-line paint heaters and thinning solvent. Therefore, the VOC emissions from the coating for all three scenarios is the same. Although the combination of thinner and heaters would result in lower viscosity of the coating than either alone. The VOC emissions resulting from the use of thinning solvent were calculated based on the average VOC content of thinning solvent and the amount of thinning solvent used at each model yard. Scenarios 1 and 3 assume that the amount of thinning solvent required is a function of the total coating usage. Therefore, the thinning solvent usage for Scenarios 1 and 3 was calculated based on lower-VOC coating usage, assuming the percent thinning remains constant. For Scenario 2, it was assumed that all thinning solvent usage associated with the three major-use coating categories could be eliminated by using in-line paint heaters. Therefore, the thinning solvent emissions from these coating categories for Scenario 2 are zero.

C.2.2 Cost of Using Lower-VOC Coatings

The costs associated with using lower-VOC coatings include the cost of the coatings and thinning solvent and the cost of any auxiliary equipment that may be used, such as in-line paint heaters. The lower-VOC coating and thinning solvent usages were calculated as described above; the associated costs were calculated by multiplying the usages by the average costs of the coatings and thinning solvent.

The annualized cost of in-line paint heaters includes the capital recovery cost, indirect costs, maintenance costs, and the cost of electricity to operate the guns. These costs are summarized in Table C-1. First, the number of in-line paint heaters had to be calculated. The number of heaters was assumed to be a function of the number of painters. Therefore, the number of painters at each model yard was estimated. Based on the shipyard survey responses, a relationship between total coating usage and the number of workers involved in painting operations was developed. The information concerning the number

TABLE C-1. IN-LINE HEATERS ANNUALIZED COSTS

	Construction				Repair			
	Extra small	Small	Medium	Large	Extra small	Small	Medium	Large
Average total coating usage, 1,000 gal/yr	8	21	48	149	10	21	38	132
Number of workers[a]	46	66	106	256	49	66	91	230
Number of painters[b]	35	49	79	192	37	49	68	173
Number of heaters	36	51	82	198	38	51	70	178
Capital (cap.) cost	$39,600	$56,100	$90,200	$217,800	$41,800	$56,100	$77,000	$195,800
Capital recovery	$10,446	$14,799	$23,795	$57,456	$11,027	$14,799	$20,313	$51,652
Maintenance (4% of cap. cost)	$1,584	$2,244	$3,608	$8,712	$1,672	$2,244	$3,080	$7,832
Indirect (4% of cap. cost)	$1,584	$2,244	$3,608	$8,712	$1,672	$2,244	$3,080	$7,832
Cost of electricity, $/yr	$11,363	$16,098	$25,883	$62,499	$11,995	$16,098	$22,096	$56,186
Total annual cost	$24,978	$35,385	$56,894	$137,379	$26,366	$35,385	$48,568	$123,502

[a] Workers involved in the coating operation (includes helpers and sprayers).

[b] Number of workers actually spraying paint.

of painters contained in the Navy responses could not be used with confidence due to the wording of the relevant questions and the lack of information concerning the use of subcontractors. A regression analysis was performed to develop a relationship between coating usage and the number of workers involved in painting at all non-Navy yards in the data base. The regression equation (which calculates the number of workers) developed is as follows:

$$34.396 + 1.4852*[(\text{total paint} + \text{thinner usage, gal})/1000]$$

Using the above formula, the total number of workers involved in painting was estimated for each model yard. A second assumption was made in estimating the number of painters actually painting (that would be using a paint gun and heater). For approximately every three workers actually spraying, there is a helper on the ground mixing paint, hooking up lines to full containers, etc. Therefore, it was estimated that 75 percent of the workers involved in painting operations are actually painting (referred to as painters). It was assumed that each painter would need one in-line paint heater. To account for the need for some backup heaters, it was assumed that a backup inventory of heaters equal to 3 percent of the number of painters would be maintained at each yard. Two in-line paint heater manufacturers (Binks and Graco) were contacted for the capital and operating costs associated with the heaters. Based on the information provided, a capital cost of $1,100 per in-line heater was assumed, as well as a 5 year life.[3,4] In calculating the capital recovery of the cost of the heaters, an interest rate of 10 percent was assumed. Based on the OAQPS Cost Manual, it was assumed that annual maintenance and indirect costs would both be 4 percent of the capital cost of the heaters.[5] Based on the vendor information, the electrical requirements of the heaters was estimated as 2.3 kilowatts.[3,4] For costing purposes, it was assumed that the in-line heaters would operate 8 hours per day, 365 days per year.

Based on information gathered from the Monthly Energy Review, the cost of electricity was assumed to be $0.047/kilowatt-hour.[6]

C.2.3 Recordkeeping and Reporting Costs

Recordkeeping and reporting costs have been estimated for baseline, maximum limits (options 1, 2, and 4), and average limits (option 3). (See Section 5.1.1 for a discussion of the control options.) In this analysis, no differentiation is made among the compliance scenarios introduced in Section 5.1.2 because there is no difference in the paints that are used under these scenarios. In addition, because there is no indication that recordkeeping and reporting would differ for construction yards versus repair yards, recordkeeping and reporting costs were estimated based only on the size of the shipyard.

The two major cost components for recordkeeping and reporting in this industry are labor and equipment. Labor costs are discussed below in Section C.2.3.1, followed by a discussion of equipment costs in Section C.2.3.2.

C.2.3.1 Labor hours and costs. The estimated labor hours and costs for baseline, maximum limits, and average limits are discussed below.

Baseline. Baseline recordkeeping and reporting is defined as that which is required of shipyards that are located in areas without marine coating regulations. At baseline, it is assumed that the large and medium model shipyards are required to prepare annual emission reports to comply with permit conditions and with section 313 of the Superfund Amendments and Reauthorization Act of 1986 (SARA 313). The small and extra small model shipyards are assumed to be below the cutoff for such reporting requirements.

Based on information from two large shipyards, it is assumed that large and medium yards typically track paint and solvent use through inventory records that are kept as a matter of course for business purposes.[7-9] The inventory records are electronically coupled with data on the VOC content (for permit reporting requirements) and toxics content (for SARA 313 reports) of the individual paints and solvents.

Baseline technical labor for tracking paint and solvent use at large and medium yards is estimated at 75 hours per year (hr/yr) in excess of the labor necessary for normal business inventory procedures, based on 50 weeks (wk) per yr and 1.5 hr/wk. (The 1.5 hr/wk is a standardized factor for "records of all measurements and information required" from the Emission Standards Division (ESD) Regulatory Procedures Manual.[10]) An additional 40 hr/yr is estimated for entering data on the VOC content of new paints into the paint data base. Preparation of the annual VOC emission report is also estimated at 40 hr/yr. Finally, refresher training on proper tracking procedures is estimated to total 4 hr/yr for two employees. Based on these labor requirements, the total baseline technical labor for recordkeeping and reporting at the large and medium model plants is estimated at 159 hr/yr. For the small and extra small model plants, where it is assumed that no reporting is required, the baseline technical labor for recordkeeping and reporting is estimated to be 0 hr/yr.

As presented in Chapter 5, the cost of baseline recordkeeping and reporting was calculated using factors from the ESD Regulatory Procedures Manual (see Table 5-10). Unless otherwise determined, management and clerical labor hours are assumed to be 5 percent and 10 percent of technical hours, respectively. Technical labor, including fringe benefits and overhead, is charged at a rate of \$33/hr, management labor is \$49/hr, and clerical labor is \$15/hr.[11] Using these factors, the baseline recordkeeping and reporting cost for large and medium model yards is calculated as follows:

$$159 \text{ hr/yr} \times [\$33/\text{hr} + (0.05 \times \$49/\text{hr}) + (0.1 \times \$15/\text{hr})] = \$5,875/\text{yr}$$

Maximum limits. Table C-2 presents a spreadsheet developed to calculate the technical labor hours and costs for the reporting and recordkeeping required under a maximum VOC limit on

TABLE C-2. ESTIMATED RECORDKEEPING AND REPORTING LABOR AND COST FOR MAXIMUM STANDARDS

A	B	C	D	E	F
	Cost Component	Large	Medium	Small	Extra Small
6	Paint usage (gal/yr)	128,000	39,000	19,000	8,000
7	Operating schedule (wk/yr)	50	50	50	50
8	Operating schedule (day/wk)	6	6	5	5
9	Total facility shifts/day	3	3	1	1
10					
11	Painting areas	10	3	2	1
12	Painting shifts/day (pt shift/day) (a)	(C11*1)	(D11*1)	(E11*1)	(F11*1)
13					
14	Field records (hr/wk/pt shift)	1.5	1.5	1.5	1.5
15	Compiling field data (hr/wk)	8	6	(E8*0.5)	0
16	Total recordkeeping (hr/wk)	(C12*C14)+C15	(D12*D14)+D15	(E12*E14)+E15	(F12*F14)+F15
17					
18	Reports per year	4	4	4	4
19	Hours per report	16	16	16	16
20					
21	Initial 1-time training(hr/yr)	(C12*2*3)	(D12*2*3)	(E12*2*3)	(F12*2*3)
22	Refresher training (hr/yr)	(C12*2*2)	(D12*2*2)	(E12*2*2)	(F12*2*2)
23					
24	Total R&R, 1st year (hr)	(C16*C7)+(C18*C19)+(C21+C22)	(D16*D7)+(D18*D19)+(D21+D22)	(E16*E7)+(E18*E19)+(E21+E22)	(F16*F7)+(F18*F19)+(F21+F22)
25	Total R&R, later years (hr/yr)	(C16*C7)+(C18*C19)+C22	(D16*D7)+(D18*D19)+D22	(E16*E7)+(E18*E19)+E22	(F16*F7)+(F18*F19)+F22
26	Average R&R over 3 yr (hr/yr)	(C24+(2*C25))/3	(D24+(2*D25))/3	(E24+(2*E25))/3	(F24+(2*F25))/3
27					
28	Cost for R&R, 1st year ($)	(C24*33)+(C24*0.05*49)+(C24*0.1*15)	(D24*33)+(D24*0.05*49)+(D24*0.1*15)	(E24*33)+(E24*0.05*49)+(E24*0.1*15)	(F24*33)+(F24*0.05*49)+(F24*0.1*15)
29	Cost for R&R, later years ($/yr)	(C25*33)+(C25*0.05*49)+(C25*0 1*15)	(D25*33)+(D25*0.05*49)+(D25*0.1*15)	(E25*33)+(E25*0.05*49)+(E25*0.1*15)	(F25*33)+(F25*0.05*49)+(F25*0.1*15)
30	Avg cost for R&R over 3 yrs ($/yr)	(C26*33)+(C26*0.05*49)+(C26*0.1*15)	(D26*33)+(D26*0.05*49)+(D26*0.1*15)	(E26*33)+(E26*0.05*49)+(E26*0.1*15)	(F26*33)+(F26*0.05*49)+(F26*0.1*15)

(a) A painting shift is defined as a shift during which painting is performed at a single painting area. Thus, for each shift at a facility, there can be up to as many painting shifts as there are painting areas at the facility.

marine coatings (options 1, 2, and 4). Table C-3 repeats the spreadsheet with all calculated values inserted. The values used in the spreadsheet were derived primarily from information received from shipyards and the ESD Regulatory Procedures Manual. Additional information on the spreadsheet can be found in Reference 12.

This methodology assumes that the amount of each paint and thinner that is used must be recorded on a daily basis in sufficient detail that a compliance determination can be made for each day. Each painting area at the shipyard is assumed to have a paint and thinner storage area from which paint and thinner are issued; the employees who oversee the storage areas record the required information for each painting shift. (A painting shift is defined as a work shift during which painting is performed at a single painting area. Thus, for each work shift that a shipyard operates, the number of painting shifts can be less than or equal to the number of painting areas at the yard.) The daily records are compiled periodically, and quarterly reports must be prepared. Initial training is required for the recordkeepers in the first year of implementation, and refresher training is required in subsequent years. Because of this variation in training costs, the total technical labor hr/yr were calculated for the initial year and subsequent years, and the average for the first three years was calculated, as well.

Based on the estimated total technical labor hr/yr, the associated costs for each model plant were calculated as presented above for the baseline cost calculations. Estimated average costs for the first 3 years range from about $5,400/yr for the extra small model plant to about $47,000/yr for the large model plant.

Average limits. For an average VOC limit on marine coatings (option 3), recordkeeping and reporting were estimated to require twice as much labor as maximum limits. Because there are no cases where average limits are applied to an entire shipyard,

TABLE C-3. ESTIMATED RECORDKEEPING AND REPORTING LABOR AND COST FOR MAXIMUM LIMITS--CALCULATED VALUES

Cost Component	Large	Medium	Small	Extra Small
Paint usage (gal/yr)	128,000	39,000	19,000	8,000
Operating schedule (wk/yr)	50	50	50	50
Operating schedule (day/wk)	6	6	5	5
Total facility shifts/day	3	3	1	1
Painting areas	10	3	2	1
Painting shifts/day (pt shift/day)	10	3	2	1
Field records (hr/wk/pt shift)	1.5	1.5	1.5	1.5
Compiling field data (hr/wk)	8	6	2.5	0
Total recordkeeping (hr/wk)	23	10.5	5.5	1.5
Reports per year	4	4	4	4
Hours per report	16	16	16	16
Initial 1-time training(hr/yr)	60	18	12	6
Refresher training (hr/yr)	40	12	8	4
Total R&R, 1st year (hr)	1,314	619	359	149
Total R&R, later years (hr/yr)	1,254	601	347	143
Average R&R over 3 yr (hr/yr)	1,274	607	351	145
Cost for R&R, 1st year ($)	48,552	22,872	13,265	5,506
Cost for R&R, later years ($/yr)	46,335	22,207	12,822	5,284
Avg cost for R&R over 3 years ($/yr)	47,074	22,429	12,969	5,358

this estimate was based on information from a shipyard that operates a spraybooth under an average limit.[13] This estimate is believed to be reasonable considering the advance planning, daily tracking, and frequent rescheduling of work that would be required to meet this type of limit.

The estimated total technical labor hr/yr and associated costs for recordkeeping and reporting at each model shipyard under an average limit are presented in Table C-4. These estimates are simply double the estimated levels for maximum limits. Accordingly, estimated average costs for the first 3 yr range from about $10,700/yr for the extra small model plant to about $94,100 for the large model plant.

C.2.3.2 Equipment costs. The equipment needed for recordkeeping and reporting consists of computer hardware and software for compiling the records and manipulating the data to generate reports. Information on equipment used for recordkeeping and reporting in this industry came from two shipyards, a large shipyard subject to baseline requirements and a medium shipyard subject to a maximum VOC limit.[7,14] The data received from these two yards and the analysis performed to determine annual costs are summarized in Table C-5. The average annual equipment cost for the yards is about $1,400.

As discussed previously, it is assumed that large and medium yards are subject to annual reporting requirements at baseline, while small and extra small yards are not. Accordingly, the large and medium model yards were assigned baseline equipment costs of $1,400/yr, while small and extra small model yards incur no such costs.

Under a maximum limit, all yards are subject to daily recordkeeping and quarterly reporting. For this analysis it is assumed that the baseline equipment costs also apply under maximum limits. For large and medium yards, it is assumed that the baseline equipment remains adequate. This assumption is supported by the fact that one of the yards that supplied information on equipment is already subject to maximum limits.[14]

TABLE C-4. ESTIMATED RECORDKEEPING AND REPORTING LABOR AND COST FOR AVERAGE LIMITS

Parameter	Large	Medium	Small	Extra Small
Total R&R, 1st year (hr)	2,628	1,238	718	298
Total R&R, later years (hr/yr)	2,508	1,202	694	286
Average R&R over 3 yr (hr/yr)	2,548	1,214	702	290
Cost for R&R, 1st year ($)	97,105	45,744	26,530	11,011
Cost for R&R, later years ($/yr)	92,671	44,414	25,643	10,568
Avg cost for R&R over 3 years ($/yr)	94,149	44,857	25,939	10,716

TABLE C-5. SUMMARY OF DATA ON EQUIPMENT COSTS

Cost Component	NORSHIPCO	NASSCO	AVERAGE ANNUAL COST
Capital Costs			
Hardware	--	$2,600	
Software			
Base price	$4,000	$500	
Customizing (a)	--	$1,320	
TOTAL	$4,000	$4,420	
Annual Costs			
Annualized capital costs (b)	$1,055	$1,166	
Annual software maintenance	$600	--	
TOTAL	$1,655	$1,166	$1,411

(a) NASSCO software customizing: 40 hr x $33/hr (technical labor rate, including fringes and overhead)

(b) Total captital costs x 0.2638 (capital recovery factor based on a 10-percent interest rate and 5-year useful life)

For small and extra small yards, it is assumed that the operations are simple enough that recordkeeping and reporting can be carried out manually. These smaller shipyards typically occupy a certain niche in the industry and generally do not use a wide range of different coatings.

For average limits, it is assumed that all yards must have computer equipment because of the complexity of planning, tracking, and demonstrating compliance. The baseline equipment is expected to be adequate for this purpose for all yards. Accordingly, equal equipment costs of $1,400/yr were assigned to all the model yards.

C.3 SPRAY BOOTH ANALYSIS

The use of add-on controls to reduce VOC emissions from spray booth coating operations was evaluated. The results of the analysis are presented in Chapter 5.2. The development of estimated spray booth flowrates and the VOC emissions from spray booths is discussed in Section C.3.1. The estimation of costs is discussed in Section C.3.2.

C.3.1 Estimated Flowrates and Spray Booth Emissions

In order to evaluate the cost effectiveness of using add-on controls on spray booths, the total VOC emissions resulting from spray booth coating operations, as well as the total flowrate that would be sent to the control device, had to be estimated. The total exhaust flowrate from the spray booths was estimated by examination of spray booth information provided in the shipyard surveys. One yard had a very low flowrate for the amount of coatings applied in booths; this outlier was eliminated from the analysis. A regression analysis was performed to obtain a relationship between total spray booth coating usage and total spray booth exhaust air flowrate. Three separate regression analyses were performed: just repair yards, just construction yards, and repair and construction yards combined. The equation based on repair and construction yards combined was used to predict the exhaust flowrates from the model yards because this equation showed the best correlation between coating usage and flow rate. The regression equation (which calculates the total spray booth exhaust flowrate) is as follows:

$$82{,}126.78 + 8.30 * (\text{spray booth coating usage, gal})$$

As discussed in Chapter 5, in addition to the predicted flowrates calculated using the regression equation, minimum expected flowrates for each of the model yards were calculated by comparing predicted and actual flowrates. This comparison was made for each of the yards that supplied complete spray booth information. Each of the actual yards was placed into a model yard category, and the ratios of the actual to the predicted flowrates of all yards in each of the categories were examined. For example, the ratios of predicted to actual flowrates for the three yards that fell into the small construction model yard category were 0.36, 2.58, and 0.18. The flowrate calculated using the regression equation was then multiplied by the smallest of the ratios in a model yard category (in this case, 0.18) to estimate the minimum expected flowrate.

The VOC emissions resulting from spray booth operations at each of the model yards were estimated based on the amount of coatings (and thinner) sprayed in booths and the average VOC content of the coatings. Because information concerning exactly which coatings were applied in each spray booth was not available, booth emissions were estimated using an average VOC content of 3.29 lb VOC/gal (minus water and exempt solvents) for the coatings, and 7.0 lb VOC/gal for the thinner.

To estimate the costs of using thermal incineration to control spray booth VOC emissions, the methodology described in the OAQPS Cost Manual was used.[5] Costs were developed for the two flowrates calculated for each model yard (that calculated using the regression equation and the minimum expected flowrate).

C.3.2 Thermal Incineration Systems Cost

Recuperative and regenerative thermal incinerators were evaluated, as discussed in Chapter 5. The spreadsheets used to estimate costs for recuperative and regenerative thermal incinerators were very similar; the spreadsheet for regenerative thermal incinerators is presented in Table C-6.

The spreadsheet and some assumptions were based on information developed as part of the Wood Furniture project. Therefore, references to information obtained as part of the Wood Furniture project are made in the following text.

C.3.2.1 Thermal Incinerator Inputs. The information necessary to calculate thermal incinerator costs for any given situation is listed under "Parameters" in the spreadsheet. This data is also listed below:

1. Volumetric Flow Rate, standard cubic feet per minute (scfm)
2. Waste Gas VOC Concentration, parts per million by volume (ppmv)
3. Heating Value of VOC's, British thermal units/scf (Btu/scf)
4. Energy Recovery (percent)
5. Incinerator Operating Temperature, degrees Fahrenheit (°F)
6. Incinerator Operating Temperature during Idle (°F)
7. Waste Gas Temperature (°F)
8. Molecular Weight of VOC (lb/lb-mole)
9. Finishing hours per shift
10. Number of shifts per day
11. Number of operating days per year
12. Number of hours idled per day
13. Warm-up period (hours)
14. Pressure drop across the control device and heat recovery unit (inches of water)

The heating value and molecular weight of the VOC's were calculated assuming the VOC's were xylene because xylene is the

PARAMETERS:

1. VOLUMETRIC FLOW RATE, (SCFM):	369,200
2. WASTE GAS VOC CONCENTRATION (PPMV):	100
3. HEATING VALUE OF VOCS (BTU/SCF):	4,980
4. ENERGY RECOVERY (%):	95
5. INCINERATOR OPERATING TEMPERATURE (F):	1,500
6. INCIN. OPERATING TEMP. DURING IDLE (F):	1,100
7. WASTE GAS TEMPERATURE (F):	77
8. MOL WEIGHT OF VOC:	106
9. MOL WEIGHT OF GAS:	29.0077
10. FINISHING HOURS/SHIFT:	8
11. SHIFTS/DAY:	1
12. DAYS/YR:	200
13. IDLING HOURS/DAY	15
14. FLOWRATE WHILE IDLING (SCFM):	55,380
13. WARM-UP PERIOD (HOURS)	1
14. PRESSURE DROP (INCHES OF WATER)	29

STEP 1: CALCULATE TOTAL WASTE GAS FLOW

O2 CONTENT OF WASTE GAS (% VOL):	21.0
DILUTION AIR REQUIRED FOR COMBUSTION (SCFM):	0
DILUTION AIR FOR SAFETY	0.0
TOTAL GAS FLOW RATE (SCFM):	369,200

STEP 2: HEAT CONTENT OF WASTE GAS (BTU/SCF):	0.50	
STEP 3: CALCULATE GAS TEMP EXIT PREHEATER :	1,429	
STEP 4: CALCULATE PREHEATER EXIT TEMP. WHILE IDLING	1,049	
STEP 5: CALC AUXILIARY FUEL REQ'D (SCFM): DURING FINISHING	1,540	
STEP 6: CALCULATE TOTAL GAS FLOW (SCFM): DURING FINISHING	370,740	
STEP 7. CALCULATE WARM-UP AUX FUEL REQ. (SCFM):	1,749	
STEP 8. CALC. WARM-UP TOTAL GAS FLOW (SCFM):	370,949	
STEP 9. CALC. AUX. GAS FLOW DURING IDLE (SCFM):	188	
STEP 10. CALC. TOTAL GAS FLOW DURING IDLE (SCFM):	55,568	
STEP 11. CALC. ANNUAL NATURAL GAS FLOW (SCFY):	202,582,081	ASSUMING 8 HR/DAY FINISHING, 15 HR/DAY IDLE, 1 HOUR WARMUP

Table C-6. Spreadsheet for Regenerative Thermal Incinerators

CAPITAL COST CALCULATIONS

DIRECT COSTS		
EQUIPMENT COST (REGENERATIVE INCIN) ($):	5,153,869	1ST QUARTER 1992 $
AUXILIARY EQUIPMENT (DUCTWORK,STACK) ($):	257,693	(ASSUMED 5% OF EQUIP. COST)
AUXILIARY COLLECTION FAN:	121,104	
INSTRUMENTATION ($):	553,267	
SALES TAX ($):	165,980	
FREIGHT ($):	276,633	
TOTAL PURCHASED EQUIP (TPE) COST ($):	6,528,546	
DIRECT INSTALLATION COSTS ($):	1,958,564	(ASSUMED 30% OF TPE)
INDIRECT COSTS ($):	2,023,849	(ASSUMED 31% OF TPE)
TOTAL CAP INVESTMENT (TCI) ($):	10,510,959	(IF FLOW <20,000 CFM, TCI=1.25*TPE)

ANNUALIZED COST CALCULATIONS

OPERATING LABOR		
OPERATOR: (.5 HR/SHIFT, $12.48/HR)	3,744	
SUPERVISOR: (15 % OF OPERATOR)	562	
MAINTENANCE: (.5 HR/SHIFT, $13.73/HR)	4,119	
MATERIAL: (100% OF MAINT. LABOR)	4,119	
UTILITIES:		
NATURAL GAS DURING FINISHING:	487,838	($3.3/1000SCF)
NATURAL GAS DURING IDLING:	111,424	($3.3/1000SCF)
NATURAL GAS DURING WARM-UP:	69,259	($3.3/1000SCF)
ELECTRICITY:	221,685	($.047/KWH)
BTU - NATURAL GAS	1.81E+11	
BTU - ELECTRICITY	1.61E+10	
BTU - TOTAL:	1.97E+11	
TOTAL DIRECT ANNUAL COST.	902,749	
INDIRECT ANNUAL COSTS		
OVERHEAD : (60% OF LABOR + MATERIALS)	7,526	
ADMINISTRATIVE: (2%*TCI)	210,219	
PROP TAX: (1%*TCI)	105,110	
INSURANCE: (1%*TCI)	105,110	
CAPITAL RECOVERY	1,710,659	(ASSUMING 10YRS, 10 %)
TOTAL	3,041,373	

Table C-6. (Continued)

main VOC in many marine coatings. The molecular weight of xylene is 0.23 lb/lb-mole. The heating value (heat of combustion) of xylene is 4,980 Btu/scf.[15]

The pressure drop across the combined control device/heat recovery unit for the thermal recuperative incinerator was calculated based on information in the OAQPS cost manual.[5] The pressure drop for the regenerative thermal incinerator was calculated based on the electricity requirements provided by the vendors contacted for the wood furniture CTG project (assuming all electricity is used by the fan).[16-27]

There are also two fields in the "Parameters" section that calculate parameters based on other input information. They are:

Molecular weight (MW) of gas. This value is calculated from the VOC concentration (conc) and the molecular weight of the VOC in the following way:

$$\text{MWgas} = \left[\frac{\text{VOC conc (ppmv)}}{1 \times 10^{6}}\right] \times [\text{MW}_{\text{VOC}}] + \frac{[(1 - \text{VOC conc \{ppmv\}})] \times (29)}{1 \times 10^{6}}$$

Flowrate while idling. Only the regenerative thermal incinerator is ever operated in idle mode. Based on vendor information, it was assumed that during idle, only 15 percent of the total flow is used.[17,23,28] Thus, the flowrate while idling is calculated as:

$$Q_{idle} = Q_{tot} \times .15$$

C.3.2.2 Thermal Incineration Calculations. The cost factors used in calculating thermal incinerator costs are presented in Table C-7. The general cost-related assumptions are summarized in Table C-8. The calculations done by the spreadsheet are presented below:

Step 1: Calculate Total Waste Gas Flow

a. Molecular oxygen (0_2) Content of the Waste Gas (Percent Vol):

TABLE C-7. CAPITAL COST FACTORS FOR THERMAL AND CATALYTIC INCINERATORS.[5]

Cost item	Factor
Direct costs	
Purchased equipment costs	
Incinerator (EC) + auxiliary equipment[a]	As estimated, A
Ductwork	0.05 A
Instrumentation[b]	0.10 A
Sales taxes	0.03 A
Freight	0.05 A
Purchased equipment cost, PEC	B = 1.23 A
Direct installation costs	
Foundations and supports	0.08 B
Handling and erection	0.14 B
Electrical	0.04 B
Piping	0.02 B
Insulation for ductwork	0.01 B
Painting	0.01 B
Direct installation cost	0.30 B
TOTAL DIRECT COST, DC	1.30 B
Indirect costs (installation)	
Engineering	0.10 B
Construction and field expenses	0.05 B
Contractor fees	0.10 B
Start-up	0.02 B
Performance test	0.01 B
Contingencies	0.03 B
Total indirect cost, IC	0.31 B
TOTAL CAPITAL INVESTMENT = TCI = DC + IC	1.61 B

[a] Ductwork internal to the unit and any other equipment normally not included with unit furnished by incinerator vendor.

[b] Instrumentation and controls often furnished with the incinerator, and thus often included in the EC.

TABLE C-8. GENERAL ANNUAL COST ASSUMPTIONS FOR ADD-ON CONTROLS

Annual operating hours:	2,000
Operating labor rate, $/hr	12.48[a]
Operator labor required, hr/8-hr shift	0.5, or as specified by vendor[b]
Supervisor cost, percent of operating labor	15[b]
Maintenance labor rate, $/hr	13.73[a] [b]
Maintenance labor required, hr/8 hr shift	0.5, or as specified by vendor[b]
Annual maintenance materials	100 percent of maintenance labor, or as specified by vendor[b]
<u>Utilities</u> Natural gas, $/1,000 scf Electricity, $/1,000 kWh	 3.3[c] 47.0[c]
Overhead, percent of operation and maintenance	60[b]
Administrative charges	2 percent TCI[b] [d]
Property taxes	1 percent TCI[b] [d]
Insurance	1 percent TCI[b] [d]
Capital recovery	CRF (TCI)[b] [d] [e]

[a] Reference 29.
[b] Reference 5.
[c] Reference 6.
[d] TCI = Total capital investment.
[e] CRF = Capital recovery factor assuming 10 percent interest.

$(1 - \text{VOC conc}/1 \times 10^6) * 0.21 * 100$

This equation assumes that the waste gas is composed of air and VOC's.

b. Dilution air required for combustion (scfm):

The OAQPS Cost Manual states that there must be at least 20 percent O_2 in the waste gas for combustion to occur (p. 3-24).[5] For all of our situations, there will always be at least 20 percent O_2, because our waste gas streams are so dilute. However, in a situation where the waste gas VOC content might be on the order of 100,000 ppmv (10 percent by vol), for example, the actual O_2 content of the waste gas would be 18.9 percent by volume. For a 1,000 scfm stream, the required additional combustion air is calculated to be 985 scfm. This corresponds to an O_2 content of the waste gas (percent by volume) of:

$$\frac{(0.21)(985\ \text{scfm})\ (\frac{\text{lbmol}}{392\ \text{ft}^3}) + (.189)(1{,}000\ \text{scfm})\ (\frac{1\ \text{lbmol}}{392\ \text{ft}^3})}{(1{,}000 + 985)\ \frac{(\text{lbmol})}{392}}$$

$$= \frac{0.528\ \text{lbmol}\ O_2\ + 0.4821}{5.06} = 20\ \text{percent}$$

<u>Dilution air required for safety</u>. According to the OAQPS Cost Manual, p. 3-26, safety codes require that the maximum VOC concentration in the waste gas stream not exceed 25 percent of the lower explosive limit (LEL) of the organic compound when a preheater is used. We conservatively assumed that the maximum allowable VOC concentration in the booth would be 10 percent of the LEL because the booths are manned. The LEL for xylene is 11,000 ppm.

A maximum allowable concentration of 10 percent of the LEL corresponds to 11,000 * 0.10 = 1,100 ppmv.

In certain situations, additional air may need to be added to the waste gas to dilute the waste gas VOC concentration to 1,100 ppmv. The cell formula is:

@ IF (Conc * Flow)/(Flow + Combustion air) < 1,100, 0, (Flow * Conc - 1,100 * Flow - 1,100 * F24)/1,100)

Dilution air for safety was not needed for any of the scenarios evaluated.

Calculate total gas flow. This field calculates the total amount of gas flowing into the incinerator. The total gas is composed of:

Input flow (waste gas) + dilution air for combustion + dilution air for safety

Step 2: Calculate Heat Content of the Waste Gas

The formula for this field is:

$$\frac{\frac{\text{VOC}}{1 \times 10^6}}{\text{Total Gas Flow}} * [\text{Initial Flowrate}] * \text{VOC heat content (Btu/scf)} = \text{Btu/scf}$$

This information is used in calculating the amount of auxiliary fuel required.

Step 3: Calculate Gas Temperature Exit Preheater

As stated in the OAQPS Cost Manual, the preheater temperature is related to the fractional energy recovery and the incinerator operating temperature and waste gas inlet temperature by the following equation:

$$\text{Energy Recovery} = \frac{T_{wo} - T_{wi}}{T_{fi} - T_{wi}}$$

where: T_{wo} = Gas preheater exit temperature

T_{wi} = Waste gas inlet temperature

T_{fi} = Incinerator operating temperature

This equation is manipulated to

$$\frac{\text{Energy Recovery}}{100} * (T_{fi} - T_{wi}) + T_{wi} = T_{wo}$$

in the spreadsheet. The same equation is used to calculate the preheater exit temperature during idle; the incinerator operating temperature is decreased, however, during idle.

Step 4a: Calculate Auxiliary Fuel Required

Auxiliary fuel use was estimated using the equation presented on page 3-32 of the OAQPS Cost Manual[5]. It is:

$$\rho_{af}\, Q_{af} = \left[\frac{\rho_{wo}\, Q_{wo}\, [C_{pmair}\,(1.1\, T_{fi} - T_{wo} - 0.1\, T_{ref}) - (-\Delta h_{cwo})}{(-\Delta h_{caf}) - 1.1\, C_{pmair}\,(T_{fi} - T_{ref})}\right]$$

where:

ρaf = density of auxiliary fuel (methane), 0.0408 lb/ft^3 @ 77°F, 1 atm

Q_{af} = natural gas flowrate, scfm

$\rho_{wo} = \rho_{wi}$ = density of the waste gas (essentially air), at 77°F, 1 atm (0.0739 lb/scf)

C_{pmair} = mean heat capacity of air

Assume 0.255 Btu/lb°F (the mean heat capacity of air between 77°F and 1375°F)

$T_{ref} = T_{af}$ = temp. ambient (Temp. auxiliary fuel) = 77°F

$-\Delta h_{cwo}$ = heat content of the waste stream, BTU/lb

$-\Delta h_{caf}$ = heat content of natural gas, 886 BTU/scf (21,081 BTU/lb)

Step 4b. Calculate Auxiliary Fuel Required During Warm-up

The vendors provided estimates of warm-up periods but did not provide estimates of fuel use during warmup. Therefore, the OAQPS cost manual methodology was used to estimate the amount of auxiliary fuel needed to warm up the incinerator, in the absence of VOC's (since no process exhaust is directed into the unit during warm-up). Based on vendor information, a recuperative thermal incinerator warm-up period of 45 minutes, using 60 percent of the total airflow, was assumed. Also based on vendor information, the regenerative thermal incinerator warm-up period was assumed to be 1 hour with full airflow.[17,23,28] The equation used to calculate the amount of auxiliary fuel required during warm-up is similar to the one used in Step 4a, except that the heat content of the waste stream, $-\Delta h_{CWO}$, is assumed zero.

Step 4c. Calculate Auxiliary Fuel Required during Idle

This field applies only to the regenerative thermal incinerator, and calculates the amount of auxiliary fuel required while the incinerator is in idle mode. Because the packing material used in regenerative thermal incinerators takes a long time to heat, vendors suggested idling the unit while not in use, rather than shutting it down completely. The unit controls finishing emissions for 8 hours per day and is warmed up for 1 hour per day; it was assumed to operate in idle mode for the remaining 15 hours per day. Based on vendor information, the incinerator operating temperature drops gradually to 1100°F during idle; only 15 percent of the total airflow is used. The amount of auxiliary fuel require during warm-up is calculated using Step 4a. However, in this case the temperature during the idle period is 1100°F, the heat content of the waste stream $-\Delta h_{CWO}$, is assumed 0 and a lower air flow is used. [17,23,28]

Step 5: Total Gas Flow=Total Waste Gas Flow + Auxiliary Fuel

The total gas flow during finishing, warm-up, and idle are calculated using the total waste gas flow plus the corresponding auxiliary fuel requirements.

The calculated annual auxiliary fuel flow, in standard cubic feet per year (SCFY), is the amount of natural gas that is required in the incinerator in a year, considering the weighted average of the gas flow during finishing, warm-up, and idle.

C.3.2.3 Capital Cost Calculations.

Equipment Costs. Equipment costs were based on pp. 3-44 and 3-45 of the OAQPS Cost Manual).[5] Equipment costs for recuperative incinerators are a function of the total gas flow through the incinerator. For 70 percent heat recovery, the equation is:

$$EC = 21,342\ Q_{tot}^{0.2500}$$

The equipment costs for regenerative thermal incinerators is an approximately linear function of total flow rate. For 95 percent heat recovery, the equation is:

$$EC = 2.204 \times 10^5 + 11.55Q_{tot}$$

For both recuperative and regenerative thermal incinerators, the equipment cost obtained using the above formulas was multiplied by Chemical Engineering Equipment cost indices of (393.7/342.5) to correct equipment costs to first quarter 1991 dollars.[30]

Auxiliary equipment (ductwork, stack). Based on the OAQPS Cost Manual, the cost of auxiliary equipment was estimated as 5 percent of the equipment cost.[5]

Auxiliary collection fan. The auxiliary collection fan was sized on a minimum gas flowrate of 500 scfm. The equation used to estimate the fan cost is:

$$\text{Fan cost (\$)} = 79.1239 * [\text{Total gas flow from Step 1 (d)}]^{0.5612} * (361.8/342.5)$$

The above equation is based on the 1988 Richardson Cost Manual.[31]

Other capital costs. Instrumentation: 10 percent of purchased and auxiliary equipment (based on OAQPS Cost Manual).[5]

Sales tax: 3 percent of purchased and auxiliary equipment (based on OAQPS Cost Manual).[5]

Freight: 5 percent of purchased and auxiliary equipment (based on OAQPS Cost Manual).[5]

Total purchased equipment cost (TPE) equals sum of the equipment, ductwork, auxiliary fan costs, instrumentation, tax and freight.

C.3.2.4 Direct Installation Costs. Direct installation costs were estimated as 30 percent of the total purchased equipment (TPE) cost (based on the OAQPS Cost Manual).[5]

Indirect installation cost. Indirect installation costs were estimated as 31 percent of the TPE cost (based on the OAQPS Cost Manual).[5]

When the maximum total gas flow was less than 20,000 scfm, then the total installation costs (direct and indirect) were calculated as 25 percent of the purchased equipment costs. In the other cases the direct and indirect installation costs were determined as described above (based on the OAQPS Cost Manual).[5]

Total capital investment. Total capital investment (TCI) is the sum of the total purchased equipment cost, direct installation costs, and indirect installation costs.

C.3.2.5 Annualized Costs. In calculating annual operating, maintenance, and supervisory labor costs, the following equations were used.

Operator: $12.48/hr x 0.5 hr/shift x shifts/day x day/year
(Assume 1 shift/day, 365 days/year)
Supervisor: 15 percent of operator
Maintenance: $13.73/hr x 0.5 hr/shift x shifts/day x day/year
Material: 100 percent of maintenance

The labor rates were based on the U. S. Industrial Outlook 1992 and the OAQPS Cost Manual.[5,29]

Utilities

Natural gas: Yearly natural gas usage (SCFY) x $\frac{\$3.3}{1{,}000\ \text{scf}}$

The yearly natural gas usage is the sum of auxiliary fuel requirements during finishing, warm-up, and idling (as applicable). To estimate electricity requirements, the formula presented on page 3-55 of the OAQPS Cost Manual was used:

$$\text{Power (fan)} = \frac{1.17 \times 10^{-4}\ Q_{tot} \Delta P}{E}$$

where:

Q_{tot} = maximum gas flow

ΔP = pressure drop, inches of H_2O, across the control device and heat recovery unit. Assumed to be 19 inches H_2O for recuperative thermal incinerators and 29 inches H_2O for regenerative thermal incinerators.

E = fan efficiency (assumed to be 60 percent)

P = power, in kW

Total electricity used during finishing, idle, warmup and cooldown was calculated using the corresponding flows and durations, and summed. The cooldown period was assumed equal to the warmup period with the corresponding flow and no auxiliary fuel. To calculate the cost of the electricity, a factor of $.047/kWh was applied to the total usage.[6]

Total Direct Annual Costs:

Sum of labor, materials, natural gas, electricity

Indirect:

Overhead: 60 percent of labor and materials

Administrative: 2 percent of TCI

Property Tax: 1 percent TCI

Insurance: 1 percent TCI

Capital Recovery: The cost of capital was annualized by multiplying the total capital investment by a capital recovery factor. For this analyses, an interest rate of 10 percent and a 10-year life were assumed, resulting in a capital recovery factor of 0.1627.

C.4 TANK ADD-ON CONTROL ANALYSIS

The feasibility and cost of using an add-on control device for tank painting operations was evaluated and is discussed in Sections 5.3.1 and 5.3.2. The results of the analysis are presented in Section 5.3.3. The development of assumptions and inputs to the tank analysis is discussed in Section C.4.1., and the sensitivity of the analysis to key assumptions is discussed in Section C.4.2.

C.4.1 Assumptions and Inputs to the Analysis

Enclosed tanks are presently vented during both blasting and painting. During blasting, the tank is vented to protect the worker and to remove the airborne particulate matter. During tank painting, the tank is ventilated to protect the worker, to maintain visibility, and to maintain an acceptable finish. Because workers are inside the tank, adequate ventilation is needed to assure their safety. Shipyards indicate that tanks are ventilated during painting operations to ensure VOC concentrations do not exceed 10 percent of the lower explosive limit (LEL).[32,33] Tanks are vented for a period of time after painting to ensure concentrations in all pockets of the tank remain below 10 percent of the LEL. Ventilation also removes dried overspray, which reduces visibility for the workers inside the tank and which can damage the finish.

The required exhaust airflow varies with the size and design of the tank, the coating used, and the number of painters. There is a very wide range of sizes of tanks that may be painted at any shipyard. Even on a single ship, there may be voids that are 3 ft high, 3 ft long, and 3 ft wide, and wing tanks that are 40 ft high, 20 ft long, and 6 ft wide, or larger.

In some construction yards, all tank painting may be done offsite. Not all repair operations involve tank painting. Because tank painting is scheduled into the overall construction or repair operation, tank painting operations may be intermittent. The number of tanks painted during a repair operation depends on many factors. Generally, only the most critical tanks in the worst condition get attention. The cost of tank painting as well as the effect on the total schedule must be considered. On a large ship, 20 to 50 tanks may be repainted during an overhaul. All the tanks may be painted simultaneously, they may be painted in sequence, or several may be painted at one time, and the remainder may not be painted until several days or even weeks later.

The variability in the number and size of tanks that may be painted at any one time in a shipyard makes evaluating add-on controls difficult. For this analysis, it was assumed that a single, stationary add-on control device would be used to control tank painting emissions. The maximum airflow that can be sent to a portable add-on control device is about 2,000 cubic feet per minute (ft^3/min). In many cases, the exhaust from a single tank may exceed 2,000 ft^3/min during tank painting operations. Due to the space constraints on a ship during construction and repair operations and the exhaust limitation associated with portable control devices, it is unlikely that an existing individual portable add-on control device would be used for each tank. It may be possible, however, by using innovative technologies, to use individual control devices for each tank.

Because the size and number of tanks being vented to the control device may vary with time, add-on controls for a range of airflows were evaluated. Costs were developed for add-on controls designed to handle airflows from 2,000 to 80,000 ft^3/min. The actual capacity required varies from hour to hour at any single shipyard.

Thermal incineration with recuperative heat recovery is considered a technically feasible add-on control alternative for controlling VOC emissions from tank painting operations. The intermittent nature of tank painting operations discourages the use of a regenerative thermal incinerator. For larger airflows (>50,000 ft^3/min), a regenerative thermal incinerator is preferable to a recuperative thermal incinerator because of the greater heat recovery. However, because the ceramic packing in a regenerative thermal incinerator must be brought up to and maintained at a minimum temperature, it is not suited for intermittent operations such as tank painting at a shipyard, according to vendors.[28,34]

In theory, catalytic incinerators and carbon adsorption systems could be used to control VOC emissions from tank painting operations. Contamination of the catalyst by the blasting residue and any poisons contained in the coatings would be a concern. The intermittent operation could significantly decrease the catalyst life. Because a wide variety of solvents are contained in the various tank coatings, reuse of the recovered solvent from a carbon adsorption system is probably not practical in this application, although the recovered solvent might have some value as a fuel or as a cleanup solvent. The precise mix of VOC's that would be present cannot be determined because it would vary from shipyard to shipyard, depending on what coatings are used, which varies with the type of ship and tank being painted. Some tank coatings contain alcohols, which are not effectively adsorbed onto carbon. Due to the uncertainty of the solvent mix, the control efficiency of a carbon adsorption system for this application cannot readily be determined. For purposes of this analysis, costs were developed only for recuperative thermal incineration systems. These costs are not expected to be significantly different from those associated with catalytic incineration or carbon adsorption systems, if such systems are feasible for this application.

Assumptions regarding design specifications and operating conditions had to be made in developing cost estimates. Because xylene is the primary VOC in marine coatings, the heating value and LEL corresponding to xylene were used in all calculations. Based on information obtained from shipyards and Occupational Safety and Health Administration (OSHA) requirements, the maximum allowable concentration of VOC's in tank exhaust was assumed to be 10 percent of the LEL.[32,33]

The actual number of hours an add-on control system would be operated would depend on the amount of time spent painting tanks, which would, in turn, depend on the number of tanks painted and the rate of painting. Shipyards were not able to provide the number of hours spent painting tanks on an annual basis. For purposes of this analysis, it was assumed that the control device would be used an average of 6 hours per shift, two shifts per day. These operating hours include the time during which painting occurs and the time after painting during which the tanks are vented for safety. In addition, a daily 45-minute warmup period was assumed, based on vendor information.[17,23,28]

In developing control system costs for tank painting, many potential complications were ignored. As mentioned previously, designing a control system to control VOC emissions from tank painting operations would be complex. The cost of engineering was calculated using the factors in the OAQPS Cost Manual; actual engineering costs for this complex application would probably be higher. Standard assumptions regarding the cost of ductwork were also made, based on the OAQPS Cost Manual. Due to the extensive lengths of flexible ductwork required, the actual cost of ductwork may be significantly higher than that estimated. The OAQPS costing methodology applies to packaged recuperative thermal incinerator units. Because of the potentially large flowrates present at a shipyard, the units would have to be field-erected instead of packaged, resulting in increased costs.[16-25] Due to the site-specific nature of such costs, they have not been included. As a result, costs for control of tank painting emissions have likely been underestimated for most facilities.

For purposes of the tank painting add-on control analysis, it was assumed that 100 percent of the tank painting VOC emissions are sent to the control device. The recuperative thermal incinerator was assumed to have a destruction efficiency of 98 percent.[16-25]

C.4.2 Sensitivity of the Tank Add-On Analysis to Key Assumptions. For airflows less than 20,000 ft^3/min, the primary annualized cost is the capital recovery of the control equipment. For airflows exceeding 20,000 ft^3/min, the primary annualized cost is the cost of fuel to run the incinerator. Fuel costs represent from 17 to 70 percent of the total annualized costs, depending on the combination of operating hours and VOC concentration assumed.

For costing purposes, an airstream concentration equal to 10 percent of the LEL was assumed. Ten percent of the LEL is the maximum allowable concentration; actual concentrations are expected to be less. To explore the impact of lower VOC concentrations, the increase in fuel usage associated with a VOC concentration of 5 percent of the LEL (instead of the 10 percent used in the original analysis) was calculated for airflows of 2,000 ft^3/min and 80,000 ft^3/min. The fuel cost for the 2,000 ft^3/min unit would increase by almost 50 percent if the actual VOC concentration was only 5 percent of the LEL. Similarly, the fuel cost for the 80,000 ft^3/min unit would also increase by almost 50 percent over that associated with a VOC concentration of 10 percent of the LEL. Because the analysis assumed a VOC concentration of 10 percent, the annualized fuel cost may have been underestimated.

Fuel costs are also a function of the total number of operating hours. As mentioned previously, for purposes of this analysis it was assumed that the incinerator would operate 12 hours per day, 365 days per year. If tank painting operations actually occur more than an average of 12 hours per day, then annual fuel usage costs have been underestimated. On the other hand, if tank painting occurs less than an average of 12 hours per day, then fuel usage costs have been overestimated. Total fuel usage is basically linear with operating hours, so if operating hours increase by 30 percent, the fuel use would also increase by 30 percent.

C.5 ENERGY IMPACTS

Energy impacts are described in Chapter 5. This section provides further information regarding the estimation of energy impacts.

The air emissions associated with the combustion of natural gas required for incinerator operation (primary emissions) and electrical power required for incinerators and heaters (secondary emissions) were calculated using the emission factors shown in Table C-9. The primary emissions were estimated in Tables 5-15a and 5-15b. As an example, from Table 5-15b, the primary particulate matter (PM) emissions associated with small model construction yards were calculated to be:

$$\frac{4.78 * 10^{10}\,\frac{\text{Btu}}{\text{yr}} * \frac{5\text{ lb}}{10^{6}\text{ft}^{3}}}{1{,}035\,\frac{\text{Btu}}{\text{ft}^{3}}} = 2.31\text{ lb/yr}$$

where:

4.78 x 10^{10} Btu/yr = Natural gas usage at small model construction yards;

5 lb/10^6 ft^3 = PM emission factor given in Table C-9; and

1,035 Btu/ft^3 = Heating value of natural gas.

The secondary air emissions that result from the generation of the electricity supplied by a coal-fired power plant were estimated in Tables 5-16 and 5-17. As an example from Table 5-16, the secondary PM emissions associated with small model construction yards were calculated to be:

$$\frac{1.17 * 10^{9}\,\frac{\text{Btu}}{\text{yr}} * \frac{1\text{ ton}}{2{,}000\text{ lb}_m} * 0.76\,\frac{\text{lb}}{\text{ton}}}{.38 * \frac{12{,}600\text{ Btu}}{\text{lb}_m}} = 92.9\text{ lb/yr}$$

where:

1.17 * 10^9 Btu/yr = bituminous coal requirement for small model construction yards;

1 ton/2,000 lb_m = conversion factor;

0.38 = thermal efficiency of power plant's generator;

12,600 Btu/lb_m = average heating value of bituminous coal; and

0.76 lb/ton = PM emission factor given in Table C-9

TABLE C-9. POLLUTANT EMISSION FACTORS[a]

Source	Emission factor, lb/10^6 ft^3				
	PM	SO_2	NO_x	CO	HC
Thermal incinerator operation (natural gas combustion)	5	0.6	140	35	5.8
	Emission factor, lb/ton				
Thermal incinerator operation (electricity generated by bituminous coal-fired power plant)	0.76	15.13	15.13	N/A[b]	N/A[b]
In-line paint heaters (electricity generated by bituminous coal-fired power plant)	0.76	15.13	15.13	N/A[b]	N/A[b]

[a] PM = particulate matter; SO_2 = sulfur dioxides, NO_x = oxides of nitrogen; CO = carbon monoxide; HC = hydrocarbons.

[b] N/A = not applicable.

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TECHNICAL REPORT DATA

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16. ABSTRACT

Volatile organic compounds (VOCs) and particulate matter including PM_{10} (that which measures 10 microns or less) are released into the atmosphere during shipbuilding and ship repair operations. This report presents alternatives from which States may select requirements for State rules. VOC reductions will result from limits that States may place on the volatile content of coatings. VOC containment equipment for ship hulls has not yet been demonstrated. Consequently, use of abatement equipment to recover or destroy the VOC from such painting is not yet practical. Abatement equipment may be used, however, to limit emissions from automated application of weld-through primers where the inherently high VOC content, rapid application rate may make the cost effectiveness of control acceptable.

The report also provides background information and general economic estimates for several control techniques. Finally, it identifies some new control techniques that are under development or in use abroad.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Shipbuilding and Ship Repair Hazardous Air Pollutants Volatile Organic Compounds Marine Coatings Surface Coating Ship Painting (Coating)	Alternative Control Techniques (ACT) Ships	

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