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Lead-Containing Paint Removal, Containment, and Disposal

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FOREWORD

This report presents a review of environmental and health regulations which affect removal of lead-containing paints from steel bridges. A review of removal and surface preparation methods, and containment are also presented. This report which presents a guide for waste reduction, control and disposal of the hazardous material generated by bridge paint removal operations will be of interest to bridge, material, and maintenance engineers concerned with bridge-painting.

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Development

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16. Abstract
Approximately 90 percent of the steel highway bridges in the United States are protected from corrosion with lead-based paints. Maintenance of the coating system requires the work to be performed in compliance with environmental and worker health/safety regulations. Conforming to these regulations has had a significant impact on procedures and cost. A comprehensive study was performed to evaluate the various factors involved with lead-paint removal. Containment and ventilation systems were studied and recommendations were developed for containment materials, design of joints, design of air inputs, negative pressure, and airflow within containment. Waste disposal is a significant issue due to long-term liability and cost. Tests were performed on hazardous waste characterization, waste minimization, methods of generating non-hazardous waste, and long-term stability of lead-containing wastes and stabilized wastes. Alternate surface preparation methods and costs were evaluated. Recyclable steel abrasive was found to be cost-competitive and to reduce the amount of debris by approximately 90 percent compared to expendable abrasive. Other surface preparation methods tested were found to have advantages and disadvantages. Advantages included reducing the amount of waste generated and worker exposure (though not below the OSHA Permissible Exposure Limit). Disadvantages included the inability to prepare all surfaces typically found on a bridge and low production rates. The cost of meeting environmental and worker health regulations has increased the cost of the average project by a factor of two or three.

17. Key Words
Lead, surface preparation, hazardous waste, containment, air quality, soil, coatings removal, worker health, abrasive blasting.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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I. INTRODUCTION

BACKGROUND

Lead-based paints have been used extensively to protect steel bridges from corrosion. Cost-effective maintenance of the corrosion protection system requires periodic maintenance of the coating and, eventually, removal and replacement. The problem of removing paint, especially lead-based paints, is a significant problem faced by highway agencies due to environmental, health, and safety concerns.

While there are alternatives to lead-based paints with equal or better performance, the majority of existing bridges have a lead-based coating system on them. Carlson reported that 185,928 of the 208,505 steel bridges (89.2 percent) carrying public roads in the National Bridge Inventory of the United States are believed to be protected with lead-based paint.(1) Appleman reported the results of a survey of 46 State highway agencies, which found that 5,960 of 7,150 bridges (83 percent) painted in the period from 1986 to 1990 had lead-based coating systems.(2) It was estimated that 5.6 to 9.3 million m^2 (60 to 100 million ft^2) are painted each year.

The most commonly used method of surface preparation was open abrasive blasting. Abrasive blasting is the most effective method for total coating removal. It was also common to "brush blast" the surface when performing maintenance coating. Open blasting is not allowed under current regulations. Yet the importance to bridge coating programs of the use of abrasive blasting cannot be overstated. Appleman estimated that 50 to 75 percent of the surface area repainted each year in the period from 1986 to 1990 was cleaned by abrasive blasting.(2) This translates to a range of between 3.0 and 7.0 million m^2 (30 to 75 million ft^2) blast-cleaned per year. In addition, abrasive blasting is the only cost-effective method to remove mill scale that is present on the vast majority of the structures painted with lead-containing paint. New high-performance coating systems require its removal before repainting.

The regulations having the greatest impact on bridge-coating maintenance relate to solid and hazardous waste, air quality, water quality, and worker health and safety. The Resource Conservation and Recovery Act (RCRA) regulates solid and hazardous waste. The debris generated during surface preparation must be collected, tested, and properly disposed. Containment is required to collect the waste regardless of whether or not it will be classified as a hazardous waste. Lead is one of the metals that can cause a waste to be classified as hazardous based on toxicity. Related regulations to RCRA are the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Superfund Amendments and Reauthorization Act (SARA). CERCLA requires that hazardous substances be controlled, releases into the environment be reported, and cleanup be performed. Lead is classified as a hazardous substance.

The Clean Air Act (CAA) regulated air quality. Lead is one of the six materials regulated. Another regulated material is fine (respirable) particulates, regardless of their chemical components. Surface preparation methods, such as abrasive blasting, that generate a large amount of dust can easily cause exceedance of this regulation unless the dust is controlled. Lead is also regulated in the Clean Water Act (CWA), so deposition of surface preparation debris containing lead into waters or storm sewers must be controlled.

While the pertinent environmental regulations were passed into law in the 1970's, enforcement of these regulations on bridge-painting projects only became prevalent in the 1980's. The issue faced initially was solid and hazardous waste. Highway agencies responded by requiring containment. Initially, containment consisted of loose-hanging drapes or tarpaulins, placed either around the work area or on the downwind side of the structure. This arrangement was quite ineffective at containing the debris, especially during abrasive blasting. Most of the debris escaped the work area. Tightening the containment increased the efficiency of collecting the debris, but made air quality worse, as the fewer entry and exit points concentrated the airborne dust. It was also noted that the atmosphere inside the containment area was heavily laden with respirable lead-containing particles that were a health hazard to the workers.

Some States went to a concept of requiring containment based on the sensitivity of the receiving environment, similar to the concept used by Ontario Ministry of Transport.(3) Less containment would be required when working on bridges in areas where there would be minimal impact on people. Hence, limited-maintenance painting funds would be maximized since less stringent containment requirements are less expensive. For example, Michigan DOT developed three categories for bridges.(4) Class 1 structures had no occupied private properties adjacent to the bridge. Containment consisted of ground tarps extending 6 m (20 ft) beyond the edge of the bridge and tarping along one or two sides if a private residence or facility was located close to the bridge, but beyond 61 m (200 ft). Class 2 bridges were those crossing a waterway with no occupied properties in close proximity to the work area. The containment requirements were similar to Class 1, with the additional requirement of placing a barge in the waterway below the work area and extending the tarps down to the barge. A floating boom or skimmer was also required. Class 3 bridges had residential, recreational, or other occupied properties in close proximity to the structure. The specification for Class 3 designation included wet abrasive blasting inside a tightly enclosed work area, followed by dry abrasive blasting after 3 days of drying. The concept of a classification system was short-lived, as regulatory agencies required additional protection of all the environment. Currently, most abrasive-blasting projects require full containment, including dust collection systems, to control dust releases to the environment and reduce dust concentrations in the enclosure.

Recently, the Occupational Safety and Health Administration (OSHA) promulgated a Construction Industry Standard on Lead. This regulation details the steps that must be taken to protect workers who are exposed to lead. Contractors must perform the functions, procedures, and requirements set forth in this standard. Highway agencies must also ensure that their maintenance workers, inspectors, and engineers are properly protected.

A major impact of these regulations has been a significant increase in the cost of bridge painting. Where the cost for total coating removal and application of a new coating system has cost between \$21.50 and \$32.30 per m^2 (\$2.00 and \$3.00 per ft^2), the additional cost of containment and waste disposal has doubled, tripled, or even quadrupled the cost of the project, depending on size, location, and complexity of the bridge. For example, Ohio DOT paid between \$27.00 and \$32.30 per m^2 (\$2.50 and \$3.00 per ft^2) prior to requiring containment.(5) The cost rose to \$86.00

to \$150.00 per m^2 (\$8.00 to \$14.00 per ft^2) when containment and recycling of abrasives were required. This experience does not include the added costs for worker protection procedures mandated by the new OSHA regulation.

The environmental and worker health issues are complex. Federal Highway Administration (FHWA), Office of Engineering, has issued three memoranda advising field offices that these items should be addressed in contracts and specifications.(6) Very little substantiated information exists on cost-effective methods to perform bridge painting in the context of environmental and worker health regulations. This research project was initiated in 1989 to address the major issues.

SCOPE OF WORK

The objectives of the research were as follows:

- To identify and evaluate available containment methods for removing lead-containing paint.
- To determine the design and operational criteria and develop concepts for negative-pressure containment systems.
- To identify and evaluate alternate cleaning methods and associated containment systems for productivity, degree of containment, and the job cost per square foot.
- To identify waste disposal sites, their capacities, and disposal costs.
- To identify and evaluate viable alternatives of disposal or use of blast residues as raw materials.

To meet the objectives of this study, the following tasks were performed:

Information Acquisition and Review

- Identify the current problem elements impacting the removal, containment, recovery, and disposal of lead-containing bridge maintenance waste.
- Identify new technology, equipment, and methods that demonstrate significant potential for successful application to the problem of removing lead-containing paint from bridge structures in a cost-effective and an environmentally acceptable manner.
- Identify the current constraints, practices, methods, and costs associated with the technology identified and assess their impact on bridge maintenance programs.

Data Reduction, Analysis, and Application

- Reduce the data collected in a manner that identifies the critical problem elements, their interrelationships, and their impact on bridge maintenance activities.
- Document the current methods, practices, and new technology being used to address these problems and assess their technical adequacy.
- Summarize the information and refine the technical approach to the research.

Identification of Waste Storage Sites and Capacities

- Identify waste storage sites which will accept blasting debris and obtain estimates of disposal costs and residual capacities of the sites.

Abrasive Reclamation

- Identify commercially available systems and treatments that will remove paint contaminants from abrasive residues.
- Identify integrated systems that are designed to perform all the operations required for abrasive blasting and provide a recycled product available for reuse.

Containment Methods and Efficiencies

- Identify and evaluate containment hardware and methods to determine containment efficiencies.
- Evaluate the major classes or types of containment methods for containment efficiency.

Alternate Cleaning Methods

- Perform an indepth analysis of alternate cleaning methods to abrasive blasting.
- Evaluate at least two of the methods showing significant promise in field operation.

Environmentally Acceptable Uses of Maintenance Debris

- Identify current State and industry practices for reuse of paint/abrasive residues.
- Identify potentially acceptable new uses of both untreated and reclaimed paint/abrasive residues.

Operational and Design Criteria for Negative-Pressure Containment Systems

- Perform operational monitoring of negative-pressure containment systems. Analyze the containment efficiencies, operational characteristics and requirements, and the cost-effectiveness.
- Prepare a conceptual system design based on operational and design requirements.
- Define and analyze the structural strength and operational requirements.
- Prepare a design guide for negative-pressure containment and blasting systems.

Many changes occurred during the course of the research that required modifications to the work plan. One major impact was the change in regulations. For example, the test method used to classify lead-containing waste was changed from the Extraction Procedure Toxicity Test (EPTOX) to the Toxicity Characteristics Leaching Procedure (TCLP). Also the "Land Ban" regulation, which forbade the land disposal of a hazardous waste became law. This required greater emphasis on methods of stabilizing bridge-painting debris than originally envisioned. The Occupational Safety and Health Administration (OSHA) developed an interim lead-in-construction standard. This standard had a significant impact on the requirements that a contractor must follow and increased cost. Greater emphasis was placed on evaluating worker exposure to lead-containing dust as part of the research.

Regulations also had an effect on the emphasis placed on evaluating containment method efficiencies. Total and partial containments were common control techniques to use when abrasive blasting at the time the research commenced. It quickly became apparent that containment systems without ventilation systems would cause exceedances of air quality regulations, and expose workers to excessively high levels of lead. Therefore, the research placed greater emphasis on evaluation of negative-pressure containment systems.

Advances that were occurring also affected the research program. For example, Steel Structures Painting Council (SSPC) developed a guide on containment of surface preparation debris.(7) Therefore, the research was altered to evaluate the requirements of the various containment and ventilation subcomponents presented in the guide.

CRITICAL ISSUES

Some critical issues became apparent during the course of the research. One issue was in the terminology and analytical measurement of lead. Confusion existed about the relationship between the differences in expression of lead concentration among the various regulations, and how these lead concentrations were related (which they are not). It was also discovered that costly decisions were being made based on a single analytical measurement, with limited knowledge of the analytical procedure being used or knowledge of the precision and accuracy of that method.

Maintenance painting strategies were identified as another critical issue. Confusion about performing bridge painting while meeting lead regulations and the high cost of performing total coating removal has resulted in a resurgence in interest in coating maintenance rather than total coating replacement. Maintaining the current coating system can reduce the life-cycle cost of the corrosion-protection coating system. However, the decision to perform coating maintenance rather than coating removal must be made on a sound, technical basis, including impact on life-cycle cost, and not solely on initial cost. Catastrophic coating failures have resulted from attempting to maintain the coating on a structure for which the existing coating system did not have the necessary mechanical and physical properties to be maintained.

Containment is required to protect the environment and collect the debris for disposal irrespective of the surface preparation method used. The requirements, efficiency, and cost of containment for bridge painting is a new concept and is not well understood. A better understanding of the operational characteristics of containment and critical parameters is badly needed.

No matter what method or extent of coating removal is performed, the waste must be collected, tested, and properly disposed. Hazardous waste disposal is expensive. Methods to minimize the amount of waste and processes to generate a non-hazardous waste have been actively pursued. The State highway agency must be very concerned about proper waste handling and disposal as the highway agency will be classified as the generator of the waste. The generator of a waste is responsible for that material *in memorium*. Improper handling or treatment can result in an initial cost savings that can be negated should toxic releases occur in the future. Waste treatment is a critical aspect of lead removal and, if done improperly, can have serious financial consequences.

Along with increased interest in waste-minimization methods and containment, came renewed interest in alternate surface preparation methods. Methods that minimized the amount of dust and debris generated would minimize containment needs and disposal cost. But alternate surface-preparation methods must be productive on typical bridge structures. Highway agencies are taking a renewed interest in alternate surface preparation methods, yet the amount of substantiated information on strengths and weaknesses of these methods is lacking.

Some of the observations made during the course of the research and the conclusion reached are:

- States need to develop bridge-painting management plans. These plans should utilize all the alternative strategies, i.e., overcoating, zone painting, and total removal, based on life-cycle costs.

- Specifications for lead paint removal should specifically address the regulations and critical requirements.

- Environmental samples, especially soil, should be obtained prior to work commencing to determine the amount of lead already existing at the site.

- Samples must be analyzed for lead using the proper laboratory procedure. The precision of the laboratory analysis must be recognized, and analysis of only one sample may lead to erroneous conclusions.

- Regulations being developed by the Environmental Protection Agency (EPA) under Title X will have a significant impact on bridge painting. States should provide comments during development of Federal and State regulations, and make plans during the grace period before these regulations become enforceable.

- State highway agencies are responsible for waste, including cost of site cleanup should lead enter the environment at a future date. Recyclable steel abrasive minimizes the waste generated and can have the greatest potential for limiting future liability if the waste is properly handled. In addition, steel abrasive can be used at blast pressure higher than most expendable abrasives, giving higher production rates and lower surface preparation costs.

- The cost differential for cleaning to Near-White (SSPC-SP10) and a high-performance coating system is small when total project and future maintenance costs are considered. Significantly reduced life-cycle costs will result from applying a longer-lasting coating system irrespective of materials cost differences.

- Significant improvements in compliance with regulations were found over the time frame of the research project. The effectiveness and efficiency of containment systems were found to be dramatically improved. Testing showed that coated fabrics are required to contain dust generated from abrasive blasting and containment fabrics lose efficiency with age and wear.

- Worker exposure to lead will exceed the Permissible Exposure Limit assigned by OSHA when removing lead-based paints typically found on bridges. Following the requirements in the OSHA Lead in Construction Industry Standard, including education of workers and good worker hygiene practices, have resulted in projects where workers' blood lead levels have remained constant or even decreased. Personal hygiene and proper safety equipment use are two facts that contribute the most to reducing worker blood lead levels.
- Controversy exists on respiratory protection devices for blasters. Even the best ventilation system will result in exposure to workers to concentrations of lead exceeding the OSHA-assigned protection factors for Type CE blast helmets. However, with proper operation and use of the Type CE blast helmet in these atmospheres, workers have not become injured as witnessed by blood lead levels. Protection factors must be re-evaluated.

II. ENVIRONMENTAL REGULATIONS

DEFINING AND MEASURING LEAD

Confusion exists in the terminology used for lead in paint. Some of the confusion relates to common usage and some relates to regulatory definitions. Confusion in terminology is further compounded by terminology used in the Department of Housing and Urban Development (HUD) guideline that relates to lead in public and Indian housing and is not applicable to industrial situations.(8) Two terms commonly used are "lead-based" and "lead-containing."

It is common to use the term "lead-based" in the industrial sector to refer to paint systems using a lead primer such as American Association of State Highway and Transportation Officials (AASHTO) Designation M72, "Red Lead Ready-Mixed Paint." This specification requires a minimum of 62.5 percent red lead (Pb_3O_4) in the pigment portion of the paint, with the pigment constituting a minimum of 66 percent by weight of the paint composition. Common bridge-coating systems used two coats of AASHTO M72 in a three- or four-coat paint system, with the preferred formulations containing up to 99.6 percent red lead in the pigment present at a minimum of 77 percent of the paint composition. Therefore, paint chips taken from existing bridge structures can contain up to 50 percent lead by weight in the dry film. Maintenance painting, consisting of spot priming and application of a total top coat, changes the total lead concentration found in paint samples. Normally, the lead concentration in paint samples taken from existing bridges that were initially painted with lead primers is in the range of 10 to 50 percent by weight.

The HUD guidelines define a lead-based paint hazard. The action level is a lead content of 1.0 mg/cm^2, or 0.5 percent by weight (5,000 parts per million (ppm)). The HUD guideline only covers public and Indian housing, and is intended to assist public housing authorities in reducing the risks of lead poisoning, especially to children under 7 years of age. Title X - Residential Lead-Based Paint Hazard Reduction Act of 1992, defines lead-based paint as paint or other surface coatings that contain lead in excess of limits established under section 302(c) of the Lead-Based Paint Poisoning Prevention Act, which are the limits used by the HUD guidelines.(9) Title X regulations will apply to bridges. However, discussions with U.S. EPA indicated the definition will apply to public buildings and not to bridges.(10)

"Lead-containing" is an expression used to indicate that there is a measurable quantity of lead in the coating, without specifying the amount of lead. The Consumer Products Safety Commission defines a paint as being lead-containing if it has more than 0.06 percent (600 ppm) lead in the dry film.(11) Therefore, "lead-free" means that the paint contains less than 600 ppm lead in the dry film and not that there is no measurable quantity of lead in the paint. This definition of "lead-containing" applies to consumer paints and products, and bans the sale of such materials. There is no similar definition or ban on industrial paints. Legislation has been introduced in Congress to limit the lead content in industrial paints to the level in the Consumer Product Safety Commission regulation, but has died in committee. The legislation did have provision for an allowance to either 0.12 or 0.19 percent incidental lead content for coatings such as zinc-rich primers, as lead is naturally occurring with zinc, and metallic zinc used as pigments contain between 500 and 2,000 ppm lead.

Lead is found in most paints. It is found in low levels in the pigments used to manufacture industrial paints.(12) Lead naphthenate was used as a drier in oil-based paints. The levels of addition normally used resulted in 750 to 3,000 ppm lead in the dry film. Certain coloring pigments as the chrome yellows (lead chromate) and bright orange (lead molybdate) have been used in formulating paints that are yellow, red, and green. Therefore, existing paint systems that are not based on a lead primer could contain about 0.1 to 5 percent lead, depending on coating type and color. Environmental, health, and safety regulations do not distinguish among the sources of lead. Therefore, even if the existing coating system does not have a lead primer, the regulations still apply.

The statutes that regulate lead use different procedures to measure the amount of lead, which are presented later in this report. Waste regulations measure leachable lead from a bulk sample of the debris. The leachable lead concentration is expressed in ppm, as the concentration is usually very low. Air quality regulations require use of a total suspended particulates (TSP) monitor that captures particles in the air from 25 to 50 μm (0.001 to 0.002 in) in diameter and smaller. The concentration is expressed in micrograms of lead per cubic meter of air ($\mu g/m^3$). The OSHA Lead in Construction Standard requires use of a personal air monitor placed in the breathing zone of the worker. The concentration of lead is expressed as micrograms of lead per cubic meter of air. Though the concentration is expressed in the same terms as U.S. EPA air quality monitoring, the method of collecting the sample is different. Therefore, different results are obtained if the two monitors are set side-by-side in the same atmosphere.

The point to be made is that the regulations measure lead by different procedures that do not correlate with each other or the total amount of lead in the existing paint. There is no specific level of lead in the existing paint that can be used to authoritatively determine whether or not a regulatory limit will be exceeded. The Steel Structures Painting Council has developed a risk assessment to assist in determining the probability of exceeding regulatory limits, which is presented in table 1.(13)

LABORATORY MEASUREMENT OF LEAD

Measured lead values can vary greatly depending on the type paint, the sampling method, the removal method (especially if the paint is heated during removal), and the analytical procedure used by the laboratory. Even the type of analytical instrument used for the tests can affect results.

Sampling is the most important step of any lead analysis. Results are only as reliable as the samples. Proper sampling and documentation includes at least the following:

- Samples must be representative. Paint must be completely scraped to the metal since the lead is usually near the steel, but not so much that steel is included in the sample. Abrasive samples should be taken in a random manner.

- Samples must be properly documented. At a minimum, sample location, date, sampling method, sampling personnel, and tests required should be recorded in a bound sample log or notebook.

Table 1. Correlation between lead concentration on surface and exposure risks.

Lead on Surface (% by Weight)	Method of Surface Prep.	Exceed Haz. Waste	Exceed OSHA PEL	Exceed NAAQS at 61 m (200 ft)
>5%	blast clean	high	very high	very high
>5%	non-blast dusting	very high	high	high
>5%	mechanical non-dusting	very high	moderate	low
1-5%	blast clean	moderate	high	high
1-5%	non-blast dusting	very high	moderate	low
1-5%	mechanical non-dusting	very high	low	very low
0.2-1.0%	blast clean	low	moderate	low
0.2-1.0%	non-blast dusting	moderate	low	very low
0.2-1.0%	mechanical non-dusting	moderate	very low	very low
0.06-0.2%	non-blast dusting	low	very low	extremely low
0.06-0.2%	mechanical non-dusting	low	extremely low	extremely low
0.06-0.2%	blast	very low	low	very low

- Samples must be properly labeled. A proper label contains the same information that was entered into the log book.

- Samples must be properly stored. If samples are to be tested just for lead, storage is simply a matter of a tightly sealed container. However, if samples are being analyzed for solvent, they must be kept cool.

The three most commonly used standard laboratory procedures for analyzing a sample for lead are: ASTM D3335, NIOSH 7082, and EPA 3050. Each of these is summarized in appendix H. It is important to note that none of these methods was designed for levels of lead commonly found in bridge paints and not all of these methods are appropriate for typical bridge paints. ASTM D3335 is intended for lead in paint, but at low concentrations (the laboratory can dilute the sample to be in the proper range for the analytical equipment). NIOSH Method 7082 is intended for measuring lead on filters obtained for exposure monitoring. EPA Method 3050 is intended for measuring lead in soils and sediments. These methods were compared and the results obtained reported in appendix A and table 2. The results of testing for this project indicate that the ASTM D3335 consistently gave the highest concentrations of lead on the same paints. NIOSH Method 7082 gave results about 75 to 80 percent of the lead concentration compared to ASTM D3335 for the same paints. EPA Method 3050 gave results about 50 percent of the lead concentration compared to ASTM D3335.

Table 2. Correlation of lead analytical methods.
(percent of lead)

Paint Sample	Analytical Method			
	ASTM D3335	NIOSH 7082	EPA 3050	Proposed PB92-114172
Bridge Paint #1	45.3	37.6	13.2	48.7
Bridge Paint #2	62.4	52.9	17.2	61.0
NIST 1579a	12.0	9.6	8.8	9.8

The EPA is proposing a new method for analysis of lead-based paints. This method, currently called PB92-114172, has not been adopted at the time of this writing. It was received in time to perform limited tests on total lead in paints for this report. It appears that the method is similar to the NIOSH 7082 method. The results using this method were slightly greater than the NIOSH 7082 method. (See table 2.) It should be noted that the variability that was found in the lab was higher than that allowed in the method. In addition, the recoveries were lower than allowed by the method. It is assumed that some of these inconsistencies will work themselves out as personnel become more familiar with the procedure. However, the authors are not convinced that the method parameters for variability can be met on typical highway paints. There was too much variability in samples to achieve only an 8- to 9- percent relative difference between two samples as required by the procedure.

Due to the many problems in lead testing, Congress required the Environmental Protection Agency (EPA) in Title X legislation to develop a laboratory accreditation program for lead testing. The EPA has chosen to recognize an existing program rather than develop one of its own. The Environmental Lead Laboratory Accreditation Program (ELLAP) administered by the American Industrial Hygiene Association (AIHA) was selected by EPA. This program requires that the laboratory participate in Environmental Lead Proficiency Analytical Testing (ELPAT). While there may be some problems with the difference in the types of paints used in the accreditation program (they are much different from typical highway paints) and some allowable methods have shortcomings, it is the program that is in place. (Since it is known that there are differences in the results of the three methods and all three methods are performed by the reference laboratories, the range of acceptable values is quite broad on the higher lead content samples tested in the program.) As soon as the summer of 1994, all aspects of the program may be in place. Currently there are about 200 laboratories in the program.

Sampling matrices can affect the results. The same paint added at the same level to different abrasives does not always test the same. Some topcoats can affect results. Generally, the effects of the abrasive are not significant on total lead concentration, except for one abrasive. Some steel grits cause the lead values to appear to be one-half of their actual value in all test methods. (See table 3.) This causes some significant problems in the steel-recycling abrasive industry. (See section on steel recycling.)

The compound effects of sample matrix and concentration of typical highway lead paints and the type of analytical instrument are not fully understood. There are basically two instruments commonly used for lead determinations—the inductively coupled plasma emission spectrophotometer (ICP) and the atomic absorption spectrophotometer (AA). A large series of samples were tested on both instruments. In general, the AA gave higher values than the ICP. However, there were some notable exceptions. At low lead values and high iron content, the ICP values were much higher than the AA values. A summary table of this work is contained in appendix A. It is important to be aware of the differences when comparing results. Often the results are not very different if all the factors that affect results are considered.

Some highway paints also contain chromium. Chromium is one of the eight metals regulated under RCRA, and OSHA has published a notice of proposed rulemaking for worker exposure to chromium. Testing of chromium was also briefly investigated. Currently, the ASTM test for chromium is ASTM D3718. It has been stated that ASTM D3335 is not suitable for chromium; however, in testing it produced results closest to ASTM D3718 compared to the other analytical methods evaluated. (See table 4.) NIOSH 7082 is said to be acceptable for chromium; however, the method appears to be insensitive to chromium concentration over the range tested. The results obtained using EPA Method 3050 were similar to the results obtained by the NIOSH method. EPA Method 3050 does not appear to be suitable for measuring chromium in paint samples, even though the method includes analysis of chromium content in soils and sediments. More work is needed on the analysis of chromium in paint, considering that it is an RCRA-regulated metal and OSHA has issued a notice of proposed regulation.

SOLID AND HAZARDOUS WASTE

The regulations which pertain to solid waste generated during surface preparation are included in the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and Superfund Amendments and Reauthorization Act of 1986 (SARA).

Resource Conservation and Recovery Act (RCRA)

RCRA was enacted to provide control over the handling and land disposal of wastes. RCRA actually consists of four interrelated programs: solid waste (Subtitle D), hazardous waste (Subtitle C), underground storage tanks (Subtitle I), and medical wastes (Subtitle J). The Federal regulations pertaining to hazardous waste can be found in the Code of Federal Regulations (CFR) under 40 CFR Parts 260 - 268.

Table 3. Lead analytical method comparison with various sampling matrices.[1]

Paint Type	Abrasive	Method ASTM D3335	Method NIOSH 7082	Method EPA 3050	Theoretical Spiked Value
Bridge paint	Mineral Sand	893	812	931	1000
Bridge paint	Mineral Sand	205	155	162	200
Bridge paint	Mineral Sand	57	44	49	50
NIST 1579a	Mineral Sand	998	1029	880	1000
NIST 1579a	Mineral Sand	188	182	182	200
NIST 1579a	Mineral Sand	54	44	50	50
Bridge paint	Steel Grit #1	423	320	420	1000
Bridge paint	Steel Grit #1	172	135	181	200
Bridge paint	Steel Grit #1	116	68	116	50
NIST 1579a	Steel Grit #1	1000	837	855	1000
NIST 1579a	Steel Grit #1	294	220	222	200
NIST 1579a	Steel Grit #1	134	96	133	50
Bridge paint	Steel Grit #2	1001	792	774	1000
Bridge paint	Steel Grit #2	196	102	120	200
Bridge paint	Steel Grit #2	84	28	53	50
NIST 1579a	Steel Grit #2	744	691	788	1000
NIST 1579a	Steel Grit #2	265	160	242	200
NIST 1579a	Steel Grit #2	58	64	92	50

[1] Results in mg Pb/kg

Table 4. Chromium concentrations by various analytical methods (percent Cr by weight).

Paint	ASTM D3718	ASTM D3335	NIOSH 7082	EPA 3050
Bridge paint #1	0.17	0.26	0.24	0.24
Bridge paint #2	0.56	0.45	0.27	0.29

The stated goals of RCRA are to protect human health and the environment, to reduce waste and conserve energy and natural resources, and to reduce or eliminate the generation of hazardous waste. In 1990, the Land Ban restriction was added to the hazardous waste regulations. The Land Ban forbade the land disposal of a hazardous waste. The waste must now be stabilized to below the characteristic level that classifies the waste as hazardous.

Hazardous waste regulations are based on "cradle-to-grave" responsibility of the generator. The definition of a generator found in 40 CFR 260.10 is "...any person, by site, whose act or process produces hazardous waste identified or listed in part 261 of this chapter and whose act first causes a hazardous waste to become subject to regulation." Discussions with U.S. EPA, RCRA Enforcement Division, indicate that the owner of the structure is considered to be the generator.(14) This responsibility cannot be fully delegated to the contractor, though the contractor may be required to store, treat, and/or dispose of the waste. The cradle-to-grave requirements of the hazardous waste regulations make the generator responsible for the waste *in memorium*. Should there be a need to clean up a waste disposal site in the future, the generators will be held responsible for their share of the cost of the cleanup.

RCRA regulations include requirements for Generators, Transporters, and Hazardous Waste Treatment, Storage, and Disposal (TSD) Facilities. The requirements for the generator include:

- Determining if the waste is hazardous.
- Obtaining EPA identification numbers.
- Preparing the manifest.
- Packaging, labeling, marking, placarding, and accumulating the waste.
- Recordkeeping and reporting.

RCRA establishes three classifications of hazardous waste generators, with some minor differences in requirements between classifications. The three categories are:

- Large Quantity Generator - generates over 1000 kg (2,200 lb) of hazardous waste per month, or stores more than 6000 kg (13,200 lb) of waste at the site at any one time.
- Small Quantity Generator - generates between 100 kg (220 lb) and 1000 kg (2,200 lb) of hazardous waste per month, or stores less than 6000 kg (13,200 lb) at the site at any one time.
- Conditionally Exempt Small Quantity Generator - generates less than 100 kg (220 lb) of

hazardous waste per month, and stores no more than 1000 kg (2,200 lb) of hazardous waste at any one time.

The differences in requirements generally relate to accumulation times, and reporting and recordkeeping requirements. Productive abrasive-blasting equipment consumes about 227 kg (500 lb) of abrasive per nozzle-hour. Therefore, most bridge-painting projects using disposable abrasives such as slags will produce enough waste in one day so that large quantity generator status will apply if the waste is found to be hazardous.

Waste Classification: It is the responsibility of the generator to determine whether or not a waste is classified as hazardous. A waste is considered to be hazardous if it meets any of four criteria:

- Ignitability.
- Corrosivity.
- Reactivity.
- Toxicity.

Of these four criteria, lead in debris from surface preparation may be classified as a hazardous waste due to its toxicity. There are eight chemical elements regulated for toxicity under Federal regulations. The toxicity characteristics of a waste are determined using a specified test method (EPA Method 1311) known as the Toxicity Characteristic Leaching Procedure (TCLP). These elements, their toxicity level (expressed as leachable content in parts per million (ppm)), and their U.S. EPA waste designation are presented in table 5.

Table 5. RCRA toxic metals.

Element	Concentration (ppm)	EPA Hazardous Waste No.
Arsenic	5.0	D004
Barium	100.0	D005
Cadmium	1.0	D006
Chromium	5.0	D007
Lead	5.0	D008
Mercury	0.2	D009
Selenium	1.0	D010
Silver	5.0	D011

Of these eight metals, lead and chromium are the two that were most commonly used in bridge paints such as AASHTO M72 and M229. Barium compounds have been used as extender pigments for coatings, though not in the AASHTO materials referenced, and in some non-lead alternative formulations. Cadmium compounds have been used as a coloring pigment. The other four metals were not used in bridge-paint formulations.

In May 1992, EPA published a major revision to the hazardous waste regulations. The proposal lowered the leachable level of lead to 1.5 ppm, increased the leachable level of chromium to 10 ppm, and increased barium to 200 ppm. The proposed change also added zinc to the list of hazardous metals with a limit of 700 ppm leachable zinc as the characteristic level. Zinc was subsequently dropped from consideration after written comments to the proposed regulation were reviewed. The final regulation has not been published as of January 1994.

Some States have added other elements to the list, such as tin, copper, and zinc. In cases where these elements have been added, the impetus has come from drinking water standards.

The concentrations presented above are leachable content of the waste, not total metal content. The TCLP test method used to measure the leachable content is a laboratory procedure that was designed to simulate the conditions found in a sanitary landfill. A sample of the waste is tumbled in an acetic acid buffer solution, filtered, and the concentration of the element of concern is measured in the leachate.

The use of the TCLP test became law for large quantity generators on September 25, 1990. The Extraction Procedure Toxicity Test (EPTOX), or EPA Method 1310, was used prior to then. When the change in testing procedures was made, lead (and arsenic) were placed in a special category. The TCLP can be used to determine if a waste is a hazardous material, but EPTOX could still be used to determine if the material was a hazardous waste and restricted from land disposal. Thus, a waste that failed the TCLP test (leachable lead equal to or greater than 5.0 ppm) but passed the EPTOX test (leachable lead less than 5.0 ppm) could be land disposed without stabilization in a hazardous waste (Subtitle C) landfill. If the leachable lead concentration is equal to or greater than 5.0 ppm, the waste must be stabilized before disposal. Whether stabilized waste goes to a Subtitle C or D landfill depends on whether the treated waste is tested by EPTOX or TCLP. Though this exemption exists, less expensive methods are available for stabilizing the waste or generating a non-hazardous waste compared to the cost of the additional laboratory testing.

Other wastes generated during bridge painting may also be classified as a hazardous waste. The debris from chemical stripping with alkaline strippers may be a corrosive hazardous waste. Paint cans may be classified as an ignitable hazardous waste though there is an exemption if there is 25 mm (1 in) or less of material in the can.

Sampling and Data Analysis: The results of a laboratory test are only as good as the samples which are submitted. The U.S. EPA test manual, which presents the analytical test methods for hazardous waste testing, also contains a detailed discussion on methods for obtaining representative samples and the number of samples needed to determine if a waste is non-hazardous.(15)

U.S. EPA test procedures require that at least four samples be randomly taken and analyzed. The results obtained are then averaged and the confidence interval (a statistical measure of variability) is calculated. If the average plus the confidence interval are below the regulatory limit (5.0 ppm for lead), the material is non-hazardous.

The equation for the confidence interval is:

$$C.I. = t_{.20}\, s_x$$

where
$t_{.20}$ = the Student "t" for 20 percent probability
s_x = standard error

While obtaining four samples for analysis is required, it is not necessary to analyze all four samples. Analysis of one sample is sufficient to classify the debris as a hazardous waste. A minimum of four samples is only needed to classify a waste as non-hazardous. Calculations show that if one sample of a waste has a leachable lead content of 10 ppm, then three other samples with 0 ppm leachable lead will result in an average plus confidence interval of 4.4 ppm. Though the waste would be classified as non-hazardous, the probability of having 0 ppm leachable lead in the other three samples is extremely low. However, this theoretical calculation does show that a single sample having a leachable lead content of 6 or 7 ppm may be obtained from a waste that is non-hazardous. So if a single sample analyzes for 7 ppm leachable lead or less, it would be advantageous to analyze the other three samples. Other examples of similar calculations can be found in the literature.(16,17)

Another important aspect of obtaining meaningful results is field sampling. A sampling plan must be developed prior to work beginning. Sampling from the site rather than from waste containers is preferred, as segregation of the waste can occur as the material is moved. A random sampling procedure is preferred. This can be performed either in space or time. For example, to perform a random sampling in space, an imaginary grid is drawn on the ground or containment deck and four squares are randomly chosen. The samples are obtained from these squares. To perform a random sampling in time, the samples are taken from the same location but at different times. This method is more appropriate in cases such as when debris is continuously cleaned up or when sampling the waste from a separator, for example. Samples are taken randomly in time as the waste drums are filled.

Obtaining a representative sample from a pile or container requires the use of a thief sampler or a trier. A thief sampler is a tube within a tube with holes on one side of each tube. The tubes are rotated so the holes do not line up. It is inserted into the pile and one tube rotated so the holes line up. Once the sample falls into the inner tube, it is rotated and withdrawn from the pile. A thief sampler works well with dry materials. A trier is basically a half tube that is inserted into a pile, rotated to cut a core, and extracted. Triers work well with moist or densely packed materials.

The TCLP test requires 100 g (3.5 oz). Therefore, each sample of waste obtained in the field should be about 300 g (10.7 oz). This will allow sufficient material for the laboratory to perform a duplicate analysis, if needed, and for laboratory quality control. Individual samples can be comprised of samples combined in the field. For example, a random sampling procedure in space may be performed, with the samples obtained from each location being combined into one master sample. The sampling procedure is then repeated for the next 3 days, resulting in four master samples.

Some States require that a Chain of Custody form accompany the samples to the laboratory. A bound field notebook is needed so that information about the sampling such as location, i.e., which part of the bridge, who performed the sampling, the date and time samples were taken, and into which containers the waste was placed, can be recorded. The Chain of Custody form that accompanies the samples to the laboratory must contain a unique sample identification number (field assigned), the date, the location of sampling, and the signature of the person who took the sample.

Site Storage: The presence of lead requires that site storage requirements for hazardous waste be followed whether or not the waste is found to be hazardous, as other lead-related regulations may apply, especially CERCLA requirements. The lead-containing debris must be stored in a manner that will not allow entry of any hazardous material into the environment.

Site storage involves grouping of materials by particular work site, even though the physical location of the storage site may be separated from the work site itself. The storage site must be secure. Security includes protection of entry of hazardous material into the environment and security of the waste from vandalism. Security begins with the choice of a suitable location. The storage site must be on well-drained ground that is not subject to flooding. The area should be enclosed by a fence or the drums secured with cables, or locked covers on gondolas or roll-offs. Prominent warning signs should be displayed around the perimeters. If the same storage site is also used for equipment and supplies, the waste containers should be segregated within the site. This can be accomplished by placing all the debris material in an assigned area within the secured site and surrounding this area with a temporary fence of ribbons or rope.

The waste must be stored in containers that are capable of being securely closed. This includes such containers as drums, gondolas, and roll-offs. The tops must be kept on the containers so that rain does not enter nor does the material blow out. The only time the containers are allowed to be opened is when material is being added or samples taken. Drums cannot be stored more than two high or two wide. Precautions must be taken so that drums do not tip over. Each container must have labels identifying the contents and dates of accumulation. The labels must be easily visible, i.e., facing the aisle.

Wastes should not be combined. For example, if a dust collector is being used, the debris from the dust collector should be stored in separate containers from gross debris. It may be found that one source of debris is hazardous while the other is not. Combining wastes may result in a larger quantity of hazardous waste.

Onsite transportation of a hazardous waste can be performed by the generator. However offsite movement of hazardous waste must be performed by a licensed hazardous waste transporter. Onsite transport is generally limited to movement of the waste from the work site to the storage area. A problem faced by many highway agencies is that many bridge maintenance painting contracts involve work on more than one bridge. A small bridge is not conducive to secure site storage of waste. A central storage area is preferred. However, a central storage area requires offsite transport, which cannot be performed by the contractor. Some transportation agencies have successfully worked with their State environmental agency to allow transport to a more secure storage area. It behooves a transportation agency to work out this potential problem prior to work beginning.

Accumulation Time: RCRA regulates the amount of time a hazardous waste can be accumulated on site. A large quantity generator can accumulate waste for no more than 90 days. A 30-day extension can be obtained from the regional EPA Administrator if problems occur. Failure to meet this time limit will result in the site being classified as an unlicensed hazardous waste storage facility, and heavy fines can result. It is important to note that according to the Federal regulations, the accumulation time starts when debris is first placed in the container, not from the time that it is tested and found to be a hazardous waste. Therefore, it is important that the date waste is first placed in a container is written on the label and waste removal be performed in a timely manner. Some highway agencies have different agreements with their State hazardous waste regulatory agencies that allow testing the waste after the work is completed, with accumulation time beginning at that point. This usually applies for projects of short duration such as overpass bridges, and not projects of long duration such as a major river crossing.

A small quantity generator is allowed to accumulate hazardous waste for 180 days, or 270 days if the waste must be transported over 333 km (200 mi) for treatment or disposal. There is no time limit for onsite storage of a non-hazardous waste.

Notification and Certification: Restricted wastes require notification and certification. At the Federal level, a restricted waste is defined as a waste restricted from land disposal, i.e., a hazardous waste. The generator's notification and certification consists of the manifest, where the identity of the waste is recorded.

Some States regulate non-hazardous, lead-containing waste. The term used to describe this waste varies by State, as does the method used to classify the waste. Some States base their regulation on total lead and other States use leachable lead concentration. Notifications and certifications vary by State.

If the waste has been treated on site, only the U.S. EPA must be notified. The notification must include the name of the facility receiving the waste, a description of the waste, the applicable treatment standard, and a certification that the waste was stabilized. The specific wording of the certification is presented in 40 CFR 268.7 (b)(5)(i). It states, "I certify under penalty of law that I have personally examined and am familiar with the treatment technology and operation of the treatment process used to support this certification and that, based on my inquiry of those individuals immediately responsible for obtaining this information, I believe that the treatment has been operated and maintained properly so as to comply with the performance levels specified in 40 CFR 268.32 or RCRA section 3004(d) without impermissible dilution of the prohibited waste. I am aware that there are significant penalties for submitting a false certification, including the possibility of fine and imprisonment."

EPA Identification Number: A hazardous waste generator must obtain an EPA identification number from the State or regional EPA office. Hazardous waste cannot be transported for treatment or disposal without this number. Different categories of EPA identification numbers are available. A **Permanent** ID number is intended for a facility that will generate a hazardous waste on a long-term, constant basis. A **Site Specific** ID number is intended for a facility that will generate a hazardous waste on a one-time basis. A **Provisional** ID number is intended for unforeseen circumstances, i.e., a diesel fuel spill, where a large amount (greater than 1000 kg (2,200 lb)) is generated.

Most transportation agencies have a Permanent ID number for disposal of hazardous wastes from their operations. But a Site-Specific ID number would be more appropriate for bridge-painting contracts as this can avoid future confusion. Site-Specific ID numbers should include all the bridges being cleaned under a contract, rather than obtaining an ID number for each bridge in the contract.

Manifest: A manifest must accompany every shipment of hazardous waste. It must be carefully and completely filled out, including a signature of an authorized representative of the generator. The generator must keep track of the documents. If proper disposal has not occurred, the generator <u>must</u> notify State or Federal EPA officials of any irregularity.

The manifest must be obtained from the State where the waste is being disposed if that State requires its use. If not, the form from the State where the waste is generated can be used. If neither of these manifests are available, a standard manifest is available from U.S. EPA (EPA Form 8700-22).

After the manifest has been filled out, the generator signs it and obtains the signature of the initial transporter and date of acceptance. A copy of this signed form must be retained. The remaining copies of the manifest are given to the transporter. There must be enough copies of the manifest for the generator, each transporter, treatment facility, disposal facility, and for the disposal facility to return to the generator.

A large quantity generator must receive the return copy of the manifest from the disposal facility within 45 days of shipment. This copy will contain the signatures of all the people who have had possession of the waste. If the return copy is not received within 35 days of initial shipment, the generator must contact the transporter or owner of the designated treatment or disposal facility to determine the status of the hazardous waste. An Exception Report must be submitted to the EPA Regional Administrator if the signed copy of the manifest is not received in 45 days. The report must include a legible copy of the initial manifest and a letter explaining the efforts taken to locate the hazardous waste and results of these efforts. A small quantity generator has 60 days to receive the signed copy. If not received, a legible copy of the manifest must be submitted with an indication that the generator has not received confirmation of delivery.

A copy of the manifest must be retained for 3 years by law, though permanent retention would be more appropriate. While many transportation agencies delegate obtaining EPA ID numbers and filling out the manifest to the contractor, the potential future liability requires that the transportation agency either be responsible for filling out and signing forms, or carefully control submission of manifests by the contractor to the project engineer.

Waste Analysis Plan: RCRA regulations allow stabilization of hazardous waste on site by the generator within the accumulation period. A waste analysis plan must be submitted to the Regional EPA Office or State 30 days prior to treatment. The waste analysis plan must include the parameters that will be analyzed and the rationale for the selection of these parameters, the test methods that will be used to test for these parameters, the sampling method that will be used to obtain representative samples, and the frequency with which the initial analysis of the waste will be reviewed or repeated. The generator is not required to receive approval of the waste analysis plan prior to starting onsite treatment, but EPA can reject the plan at any time. Simple methods of stabilizing lead-containing debris have been identified and are presented in the next section. Meetings with EPA on the Federal level have indicated that acceptance of waste analysis plans will be done at the local level, and broad-range approval will not be given at the national level.

Biennial Report: A generator who ships any hazardous waste off site to a treatment, storage, or disposal facility must submit a biennial report to the EPA Regional Administrator by March 1 of each year. Many States require this report to be submitted annually. The report must include a list of each transporter of hazardous waste and disposal facility to which waste was sent, a description of the efforts undertaken during the year to reduce the volume and toxicity of waste generated, and a description of changes in volume and toxicity actually achieved during the year in comparison to previous years.

Contingency Plan: A written Preparedness, Prevention, and Contingency Plan (PPCP) must be on site and readily available for inspection. This plan goes into great detail as to emergency procedures and spill procedures that must be used. While the plan must be detailed, the procedures used for spills are generally quite simple. In most cases, picking up spilled debris with a shovel and placing it in a barrel is sufficient. As a matter of convenience, it also usually contains the written procedure for storage and handling of hazardous waste. The plan is needed when working with a hazardous substance, and is not related to whether or not the waste is classified as hazardous.

Employee Training: The generator must make sure that all employees, either his own or those of someone else, who can or will have contact with the hazardous waste be trained in the handling of that waste (40 CFR 262.34(a)(4)). This training usually takes about 4 h. At the completion of the course, attendees are given a card that certifies that they have been trained. All employees, including supervisors, should be trained.

CERCLA & SARA

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is another act that has pronounced effects on lead-removal projects. CERCLA requires that hazardous substances be controlled. Anytime there is a release of a reportable quantity of a hazardous substance, EPA must be notified. Obviously, the definition of a hazardous substance and a reportable quantity are vitally important.

A hazardous substance is defined as: any RCRA hazardous waste; substances regulated in the Clean Water Act and the Clean Air Act; or any substance that can reasonably be anticipated to cause illness or deformation in any organism. Given this definition, it is reasonable to assume that any lead, whether hazardous waste or not, would be a hazardous substance as defined by CERCLA.

A reportable quantity is defined as a release of 4.5 kg (10 lb) or more of lead with a particle diameter of 100 μm (4 mils) or less into the air, water, or soil in a 24-h period provided the percentage of lead in the paint is known. If the percentage is not known, then a reportable quantity is 4.5 kg or more of the waste. When lead is removed via abrasive blasting, much of it is pulverized to a particle size of 100 μm or less. Given this definition and the lead content of paints typically found on structures, it is reasonable to conclude that blasting about 46.5 m^2 (500 ft^2) of structure in 1 day in an uncontained manner could result in a violation of CERCLA. This amount of blasting could discharge 4.5 kg of lead to the environment, though it all would not be 100 μm or less in size. CERCLA violations can occur in other manners, such as spills when waste is being transferred from a collection unit to a waste container. Therefore, good housekeeping practices are needed when dealing with lead-containing debris.

The Superfund Amendments and Reauthorization Act (SARA) extended CERCLA and increased the size of the fund for cleanup. It also requires notification of State and local authorities if releases of more than 4.5 kg of lead, as defined above, occurs. CERCLA and SARA regulations are found in 40 CFR 300 to 373.

AIR QUALITY

The Clean Air Act, found in 40 CFR Parts 50 through 99, addresses emissions into the atmosphere. The EPA has two major concerns about air quality—total particulates and specific constituents. Lead is one of the specific constituents regulated. Because of these concerns and the fact that blasting and painting can generate large quantities of dust and toxic materials, States can expect much closer scrutiny of bridge-painting operations. They use two different air monitoring techniques to determine if air quality limits are being met.

Regulations

Particulates: The regulation on particulate matter is found in 40 CFR 50.6, National Primary and Secondary Air Quality Standards for Particulate Matter. The definition of particulate matter as it relates to thisstandard is any material, regardless of its chemical composition, with an aerodynamic diameter equal to or less than a nominal 10 μm. Concentrations of particulates in the air are measured using a high-volume air sampler equipped with a PM_{10} collection head. Particulates that are 10 μm diameter or less are the respirable fraction that will get into the lungs if inhaled. The maximum allowable concentration of particulates in the air is 150 $\mu g/m^3$ in a 24-h period.

Lead: The regulation on lead emissions is found in 40 CFR 50.12. The National Primary and Secondary Ambient Air Quality Standard for Lead is 1.5 $\mu g/m^3$, maximum arithmetic mean averaged over a calendar quarter. There is a possibility that this will be reduced to 0.75 $\mu g/m^3$ as a 30-day average. Measurement of air quality for lead is performed with a high volume air sampler equipped with a total suspended particulates (TSP) head. The TSP head collects particles up to approximately 50 μm in diameter.

Conforming With Air Quality Regulations

Implementing the National Ambient Air Quality Standards (NAAQS) to bridge painting does present some problems. Besides placement of the monitors (which is discussed below), the way the results will be interpreted by the State Air Quality Board must be determined. The Federal regulations on NAAQS are much more explicit on stationary sources, such as plant emissions, than on mobile sources, such as bridge painting.

The NAAQS for particulates are based on monitoring for 24 h. While 24-h monitoring is achievable, security of the monitors is questionable at many bridge sites, especially in urban areas. Recommendations have been developed to convert the NAAQS requirements for particulates to shorter monitoring periods such as 8 h.(17) As background particulate levels would be significantly lower than during blasting, the proper correction is to factor in the background level for the time when no work is performed. For a background PM_{10} level of zero (0), a measured PM_{10} particulate level of 450 $\mu g/m^3$ for an 8-h shift would meet the requirement of 150 $\mu g/m^3$ for a 24-h day. The actual background level must be measured to determine the allowable level during blasting.

Conversion of the lead standard to bridge painting is a little more difficult, as the standard is presently based on a 90-day average. On any given day, the level may be much higher than the 1.5 $\mu g/m^3$ requirement, provided the 90-day average is achieved. Assuming very low background lead levels, some regulators are allowing discharges of higher levels of lead for periods of short duration. Typically, the accepted level is increased to 4.5 $\mu g/m^3$ per day since blasting and monitoring is done for only 8 h.

This level is further increased by a factor because the blasting operations are rarely performed continuously for 90 days in a calendar quarter. The anticipated number of blasting days is divided into 90 days. This factor is then multiplied by the 4.5 $\mu g/m^3$. Using this technique, a job that will require 30 days of blasting would be allowed to emit lead at a level of 13.5 $\mu g/m^3$ for an 8-h monitoring period.

Allegheny County (PA) is one of the few locales that has air quality requirements specifically for abrasive blasting. The Allegheny County Health Department limits are 150 $\mu g/m^3$ per 24-h day for particulates and 10 $\mu g/m^3$ per 8-h day for lead with no exceedance over 25 $\mu g/m^3$ allowed at any time. Allegheny County Health Department representatives indicated that their reason for allowing 10 $\mu g/m^3$ per 8-h day for lead was based, in part, on the fact that abrasive blasting is a one-time operation and not a continual emission as would be coming from a power plant, for example. Their opinion was that the limit was practical and achievable.

Monitoring Air Quality

Compliance with the air quality regulations requires the use of high-volume air samplers. Both PM_{10} and TSP monitors must be used to conform with the requirements of the Clean Air Act for particulates and lead. The cost of air monitoring can be expensive, about $500 to $1,500 per day depending upon location. The number of firms with the expertise to perform air sampling is limited, and equipment may not be available when needed. The industry has been evaluating other methods to determine compliance, such as use of personal air samplers and visual emissions. While visual emissions will not confirm conformance, such a technique can assist inspectors in deciding whether air monitoring is needed.

Monitor Operation: The operation procedures for both PM_{10} and TSP monitors are essentially the same; the only difference is the design of the head. The monitor consists of a high-volume pump that draws air through a piece of special filter paper. The filter papers are equilibrated in a controlled environment for 24 h and then weighed. The filters are placed in the monitor where a constant air flow through the filter is maintained at 1.1 m^3/min (40 ft^3/min). The time the monitor is in operation is recorded on a strip chart. After the monitoring period, the filter paper is returned to the laboratory, re-equilibrated for 24 h, and weighed. The weight increase and known air flow (corrected to standard conditions) are used to calculate the weight of particulates per cubic meter of air. For lead, a piece of the filter paper is cut out, extracted in acid, and the lead concentration in solution is measured using standard laboratory procedures. The quickest results could be available within 2 days after the test was performed, as transportation to the laboratory and a 24-h equilibration of the filter paper are required.

Placement of Monitors: The placement of monitors will have a significant effect on results. Guidance for placement of monitors is presented in 40 CFR 58, Appendix E. The specific requirements for location of the monitors are:

- The sampler inlet should be within a range of 2.0 to 7.0 m (6.5 to 23 ft) above the ground.
- The sampler should be located away from obstacles such as buildings, such that the distance between the sampler and the obstruction is at least twice the height that the obstacle protrudes above the sampler.
- There should be unrestricted air flow in a minimum 270-degree arc around the sampler.
- There should be a clear line of site between the work site and monitor with no obstructions such as trees. The sampler should be 20 m (66 ft) from the drip line of any trees.
- Automobile traffic can affect results and must be considered in placement of the monitors. This distance may be as far as 50 to100 m (165 to 330 ft) for lead monitors (TSP) and as far as 162 m (530 ft) for particulate monitors (PM_{10}).

These detailed requirements are difficult to comply with in a highway environment while still remaining on the right-of-way. Therefore, in questioning the EPA, it appears that acceptable monitor placement will be at the edge of the property line (right-of-way) at the point of maximum impact. This meets the intent of the Clean Air Act, which is concerned about public health and welfare, i.e., where the public has access. This does not solve the problem of placing monitors at a sufficient distance so results would not be affected by automobile traffic.

Another consideration in placing monitors is the height of the structure. Placing monitors near a high structure will result in the dust plume passing over the monitors. The higher the structure, the less chance there is for exceeding air quality regulations at ground level as the dust plume is dispersed over a larger area.

A minimum of two sets of monitors is needed, one set placed downwind from the work site and the other set placed upwind. The upwind monitors should be sufficiently far from the work site so as not to be affected by the blasting operation. These monitors measure the background concentrations.

Sedar and Patel have presented guidance on monitor placement to meet Allegheny County Health Department regulations.(18) Two sets of monitors (PM_{10} and TSP) are used, both placed downwind of the abrasive-blasting operation. The close set of monitors are placed at the nearest critical receptor, i.e., a residence, school, church, business, or other public or private property. The far set of monitors are placed at a point where 25 percent of the original particles' concentration is depleted by dry deposition. A table is presented in the article giving the proper distance based on height of the structure with the proviso that this distance is wind-speed dependent.

Monitoring frequency for jobs such as blast cleaning are not clearly defined in the regulations. Common approaches being taken include:

- Monitoring for the duration of the job.
- Monitoring at the initiation of the job for about a week to confirm compliance with the regulations.
- Monitoring randomly throughout the project.
- Monitoring only when there are complaints or compliance is questioned.

Monitoring frequency is a decision that must be made prior to work beginning. The frequency chosen is to be dependent upon the sensitivity of the locale where work is being performed, the expected duration of the project, and local regulations.

Other Monitoring Methods: The Clean Air Act allows for use of monitors other than PM_{10} or TSP monitors if others can be shown to be equivalent. The procedures to demonstrate equivalency are listed in 40 CFR 53. There are less expensive methods, i.e., the use of 37-mm (1.5-in) breathing zone sample cartridges with a 10- to 15-L/min (2.7- to 4-gal/min) pump.

A feasibility study was performed to compare different types of air monitors and is reported in appendix B. The results obtained indicated no correlation between any of the monitors and results from the TSP control.

SSPC Guide 6I (CON) presents a method for measuring emissions using air monitors for the protection of all personnel. One monitor is place inside containment with additional monitors placed immediately outside containment. The specifier must select an acceptance criterium on the percent reduction in emissions outside the containment. At present, insufficient data exists to determine the percentage reduction sufficient to meet NAAQS. However, a high level of emission reduction increases the probability that NAAQS limits will not be exceeded.

The personal air samplers could also be used close to containment (a few feet from a seam or tarp). This then could be used at a given site to establish a simple method of quality control for containment. Regulators in some areas have accepted 37-mm (1.5-in) cartridge monitoring if the equipment is located in the worst-case area. The fact is they are not and will not be recognized by the EPA unless the acceptance criteria in 40 CFR 53.33 is modified. Work comparing monitors is contained in appendix B.

Visible Emissions: Another method of assessing emissions is by visual observation. Visual assessment has the advantage of immediate feedback, but does not comply with NAAQS. Appendix A of 40 CFR 60, Standards of Performance for New Stationary Sources, presents two methods for assessing emissions. One method is based on the opacity of the plume and the other method is based on duration of emissions.

Method 9, Visual Determination of the Opacity of Emissions from Stationary Sources, is used to evaluate the opacity of the plume, i.e., the degree to which the transmission of light is reduced. Determining the opacity of a plume is a subjective evaluation, and personnel making these observations must be trained and certified. Certification under Method 9 is valid for only 6 months, at which time recertification must be obtained. The actual assessment procedure is presented in Method 9.

Method 22, Visual Determination of Fugitive Emissions from Material Sources and Smoke Emissions from Fires, requires measuring the amount of time visual emissions occur, regardless of opacity. Some training is needed, though personnel do not require certification. Observations are made for 15- to 20-min periods with rest breaks in between. The accumulated time of all visible emissions within the observation periods are reported. Method 22 is more applicable to bridge-painting projects than Method 9.

SSPC Guide 6I(CON) includes provisions for evaluating the effectiveness of containment devices. One of the evaluation methods presented for evaluating containment is an allowable time for visible emissions. Classifications of emissions are:

Level 0: No visible emission.
Level 1: Random emissions no more than 1 percent of the work day (5 min in 8 h).
Level 2: Random emissions no more than 5 percent of the work day (24 min in 8 h).
Level 3: Random emission of no more than 10 percent of the work day (48 minutes in 8 h).
Level 4: Unrestricted emissions.

The advantage of this method is immediate feedback compared to results from actual air monitoring that can take days or weeks to receive. This method has not been correlated to results from actual monitoring. But it does present a simple method for site personnel to evaluate the efficacy of a containment device in order to make a decision on whether emissions are too great and work should be suspended, or actual monitoring is needed.

SOIL

Currently, there are no limits established for lead in soil. The only guidance available is in a U.S. EPA Office of Solid Waste and Emergency Response Directive that establishes a level of 500 to 1,000 ppm total lead for cleanup (closure) at superfund sites when the use of the land will be residential. Some State environmental agencies consider painting projects that remove lead-based paint to require a site closure. U.S. EPA is under congressional mandate in Title X, The Residential Lead-Based Paint Hazard Reduction Act of 1992, of the Housing and Community Development Act of 1992 to define lead-contaminated soil. Indications are that this definition will apply to housing and not to industrial settings.

Lead in soil presents some serious problems for the highway industry. The lead levels in soils in the right-of-way are generally much higher than average soil lead levels found away from roads. The lead from leaded gas is still present and although it is usually not very leachable, it does generate high values in total lead analyses. For this reason, it is imperative that pre-job soil samples be obtained to determine the background lead levels in the soil near the project site.

If a project was completed and a complaint was filed, the only way to determine if significant or harmful amounts of lead were released to the environment would be to measure total lead in the area and compare these values to average values. This presents a problem, since average values for a State may be 10 to 50 ppm, while average values in the highway environment may be 200 to 2,000 ppm. The average lead concentration in soils in urban areas may be several thousand ppm. If the contractor is forced to clean up to average State values, he may have to remove many cubic yards of soil. If he has to clean up to the pre-job condition, a thorough raking to disturb the soil, followed by a vacuuming, probably would suffice.

It is in the Transportation Department's best interest to obtain soil samples prior to painting personnel's arrival on site. While these samples do not have to be tested initially, they should be thoroughly documented and properly stored. If contamination from the project is questioned, these samples can be tested along with the post-project samples to define the order of magnitude of the problem. The following procedure is recommended:

1. Draw a plan view sketch of the structure, including distinguishing landmarks, traffic flow, etc.

2. Select a number of locations, identifying each with a unique sample number, and marking it on the sketch. There is no required number of samples and good judgment is required. About 20 locations are sufficient for a typical grade separation. Four of these should be in an approximate 30-m (100-ft) radius around the structure and another 4 in an approximate 15-m (50-ft) radius, with the remaining 12 samples inside the 15-m (50-ft) radius. Of the 12 locations, 6 should be very close to the structure; 3 should be taken from below the structure if possible.

3. Obtain soil samples at each documented location as follows:

    - Draw an imaginary 0.3-m (1-ft) square on the ground.

- Remove a 12-mm- (½-in-) deep by 19-mm- (¾-in-) diameter sample from each corner and from the center of the imaginary square. Combine the five plugs as one sample.
- Fill in the holes so there are no depressions in the ground.
- Label the sample, recording the following on the sample label and in a bound field log book:

  - Sample number.
  - Date.
  - Project location.
  - Sample location.
  - Name of sampler.
  - Organizational affiliation of sampler.
  - Special comments.

- Carefully dry out all samples.

  Moist samples stored for long periods not only can smell very bad, but also tend to grow organisms. The drying can be easily performed. The samples should be transferred to drying containers or storage jars. (A 115- to 227-g (4- to 8-oz) wide-mouth container is recommended.) Once the samples are transferred to these containers and they are properly labeled, a couple of hours in a low-temperature oven or repeated 1-min exposures in a microwave oven will adequately dry out the samples. If these are not available, place the jars in a large closed box and leave the jars uncovered. After a couple of days the samples should be sufficiently dry.

  The field drying procedures are not necessary if samples are to be immediately analyzed by a laboratory. The samples will be dried by the laboratory.

- When the project is completed or a complaint is registered, return to the same locations and repeat the process.

  Post-project sampling can be performed anytime. Therefore it is not necessary to sample immediately following the project unless there is reason to believe that lead contamination is occurring from some other source. While post-job samples are the most conservative procedures, most agencies perform post-sampling, but actually test the pre- and post-samples only if the need arises. Agencies should make sure pre-project samples are not discarded until there is no possibility of a problem. Samples should be retained for at least 3 years. To properly sample and document a site takes approximately 3 h.

WATER

Regulations covering water quality may impact a bridge-painting project if the bridge is over water, water washing was being performed, or a wet method of cleaning such as water blasting or wet abrasive blasting was being used. Besides the Clean Water Act, other regulations pertaining to drinking water standards or aquatic life may be invoked. Local authorities need to be contacted as many of their regulations are under local control rather than being a part of Federal standards.

Clean Water Act

The Clean Water Act (CWA) can be found in 40 CFR Parts 100 to 149. The parts of the Act that affect bridge-painting projects are the National Pollution Discharge Elimination System (NPDES) and Storm Water Discharges. NPDES requires a permit for the discharge of a pollutant from a point source. Bridge painting does not fall into the categories of discharges discussed in the CWA, though citations for not having a permit would most likely be issued if such discharges occurred.

The Clean Water Act does contain a list of hazardous substances and their reportable quantities. A number of lead compounds are listed, though none of them are found in anti-corrosive paints. All lead compounds in the regulation have reportable quantities of 4.5 kg (10 lb) in a 24-h period. Discharges greater than this must be reported to the U.S. EPA National Response Center and appropriate State and local authorities.

WATER AND AQUATIC LIFE STUDIES WITH LEAD BRIDGE PAINTS

While some water quality regulations restrict specific compounds of lead and others do not, the question of potential water pollution and the effect on aquatic life from compounds present in bridge paints has been a subject of study. Snyder and Bendersky found no information in the literature that indicated the lead compounds used as anti-corrosive pigments contributed to increased lead levels in water.(19) Based on equilibrium calculations, they concluded that solubility would be low if the pH of the water was above 5.4. Sulfates and carbonates found in natural waters would contribute to decreased solubility of lead compounds, as they would react to form insoluble compounds. The situations that would contribute to increased lead levels would be low pH in soft water, and lakes (where lead from all sources would remain after being deposited).

Parks and Winters examined the effect of blast-cleaning debris on water quality generated during the repainting of the Middle River Bridge near Stockton, CA.(20) Samples of lead-containing debris were placed in distilled water (pH 6.5) and Middle River water (pH 8.2), and agitated daily. No increase in lead, iron, or chromium was found after 3 years of exposure. Samples were also taken of the river water for a period of 4 years after the blast-cleaning work was completed. Parks and Winters reported no significant difference in concentrations of lead, iron, chromium, or aluminum when comparing upstream samples to downstream samples.

Partial containment was used during repainting of the Middle River Bridge, so blast-cleaning debris was found in the sediment. Abrasive debris was found on the river bottom 4 years after the repainting was completed. Generally, the abrasives remained within 30 m (100 ft) of the bridge with decreasing amounts downstream to about 152 m (500 ft) from the bridge. Most of the abrasive found was either close to the banks or near bridge piers where the water flow was low.

The debris that was deposited in the Middle River did not significantly impact sediment loading. Smaller streams or bodies of water may be impacted by abrasive-blasting debris by altering the benthic (bottom) habitat. Kramme, Rolan, and Smith presented a procedure for assessing water quality impacts from highway maintenance practices, including bridge painting.(21) The first step recommended was to determine the increased sediment load due to the surface preparation activity. Next, the water body habitat was assessed by evaluating the water quality, fish species, and diversity of benthic life. A fish species association adapted by the U.S. Army Corps of Engineers was used to relate fish species present to water quality. A prediction was made of the effects the expected disturbance would have in relation to habitat loss, alteration, or displacement. The last step was assessing the value of the disturbed habitat and determining if the difference in resource value constitutes a significant impact. If a significant impact was predicted, control measures during abrasive blasting are recommended. Today, surface preparation without containment would not be permitted.

Reviewing the effects of lead paint removal on aquatic life, Snyder and Bendersky stated that there was no biological magnification of lead in aquatic food chains according to the information available in the literature.(19) They stated that aquatic biota in urban streams have many times more lead than biota in rural streams, and the lead in aquatic organisms was related to the amount of contact with bottom sediments containing high lead concentrations. Therefore, organisms in the benthic zone have the highest lead concentrations, while those in the trophic level have the lowest lead concentration.

Parks and Winters found no effect on aquatic life from the cleaning operations of the Middle River Bridge.(20) However, the large volume of water (4188 m^3/s (148,000 ft^3/s)) may have contributed to dilution of any harmful materials.

Thorpe reported on a before-and-after assessment conducted when bridge cleaning was performed in North Carolina.(22) Lead, zinc, and aluminum in sediment and benthic macroinvertebrates were measured and the effect on the composition and abundance of the macroinvertebrate community was investigated. A site under the bridge and two downstream locations were examined. No short-term effect was found at these locations.

Hunt and Gidley performed bioassays on blasting abrasives, paint chips (basic lead silicochromate, red lead/aluminum, and blast abrasive from removal of a red lead/aluminum system), surface-cleaning compounds, and new paint systems.(23) The bioassays were performed on green algae (*Selenastrum capricornutum*), water fleas (*Daphnia magna*), pulmonate snails (*Physa gyrina*), rainbow trout (*Salmo gairdneri*), and fathead minnow (*Pimephales promelas*). The most toxic materials found were the surface-cleaning compounds used to pre-wash the bridge before blast cleaning. The blast-cleaning abrasives were found to have different levels of toxicity to the species examined, with the results ranging from innocuous to somewhat toxic. The lead-based paints examined were found to cause toxic effects at some level, though the test results for some species indicated another material in the paint chip besides the lead was responsible for the effect found.

Control Technology

The literature on water quality and aquatic life tend to indicate that anti-corrosive lead pigments have very little detrimental effect. However, allowing debris to fall into the water can affect businesses and communities downstream from the work site. Care should be taken, especially when working over water. Dust escaping from containment will land on the water and present an unsightly situation. One research study concluded that the dust particles were poorly wetted and tended to float on the surface for a considerable distance.(24) More and more, the use of booms downstream from the bridge has been specified.

TITLE X

The Residential Lead-Based Paint Reduction Act of 1992, commonly referred to as Title X, specifically includes bridges among the items that fall under the regulation. Title X has a number of sections that have impacted, or will impact, bridge painting. It required OSHA to promulgate an interim lead standard for the construction industry, which became effective June 3, 1993. (See the next section.) It also established a laboratory accreditation program for laboratories analyzing lead in paint, soil, and dust. This program must be established within 2 years. Once established, only accredited laboratories may be used for lead analysis.

Title X also amended the Toxic Substances Control Act (TSCA) and directed U.S. EPA to promulgate regulations to ensure that individuals engaged in lead-based paint activities are properly trained, that the training programs are accredited, and that contractors are certified. Accreditation is to be at the State level. EPA has 18 months to develop a model State program. State programs submitted for approval must be as protective as the U.S. EPA model program to be approved.

As the proposed regulation has not been made public at this time, the extent of the accreditation requirements for those involved with bridge painting has not been established. Discussions with U.S. EPA officials indicate that the training and certification of bridge painters will be divided into two categories—workers and supervisors.(10) Workers will be required to take a 3- or 4- day course, and supervisors will be required to take a 4- or 5-day course. In addition to the course examinations, a national exam will be required for supervisors. Only certified workers will be allowed to work on lead-paint removal projects beginning 2 years after the regulation is published. As the proposed regulation has yet to be published when this report was prepared, the earliest date appears to be late 1996 or early 1997.

Of major concern is the indication that certification of workers will be at the State level. Unless there is reciprocity among States, workers and supervisors may have to take the same or similar course in each State where they work. The cost of the training and certifications will most likely affect labor costs. There may also be a shortage of workers with State certification, which will further impact the ability of contractors to get work performed. Indications are that reciprocity will be promoted, but may only occur on a regional basis. The full impact of this portion of Title X remains to be seen, as contractors must weigh the cost of training and certification versus the anticipated amount of work in each State.

WORKER HEALTH AND SAFETY

In general, the painting contractor is responsible for the worker's health and safety. The State highway agency has similar responsibilities for their own employees. OSHA regulations are quite complex, and neither the State highway agency nor the contractor may be completely familiar with the requirements. This has resulted in contractor defaults, work stoppages, and an increase in claims. FHWA, through three memoranda, has pointed out the need to address worker safety (and environmental) issues in bridge-painting contracts, and has recommended holding pre-bid conferences to ensure worker protection and reduce the potential for construction claims.(3)

While OSHA has been working on a Lead in Construction Industry standard for a few years, Title X legislation required OSHA to issue a standard within 6 months of signing of the legislation. OSHA did issue an interim final rule, effective June 3, 1993. This standard, 29 CFR 1926.62, is quite similar to the lead standard for general industry (29 CFR 1910.1025) and is quite detailed. A chart reviewing the requirements is presented in appendix K.

Definitions

In the definitions section of the standard, OSHA reinforced the need for a "competent person" as found in other OSHA construction industry standards. A competent person is defined as one who is capable of identifying existing and predictable lead hazards in the surroundings or working conditions **and** who has authorization to take prompt corrective measures to eliminate them.

Action level is also defined in this section. Action level means employee exposure, without regard to use of respirators, to an airborne concentration of lead of 30 $\mu g/m^3$ of air, calculated as an 8-h time weighted average. If an employee is exposed above the action level, some requirements of the standard, such as medical surveillance, medical removal protection, hygiene facilities and practices, training, and recordkeeping, must be followed.

Permissible Exposure Limit

An employer must ensure that no employee is exposed above the Permissible Exposure Limit (PEL), which is 50$\mu g/m^3$ of air for lead. The allowable exposure is reduced as a time weighted average (TWA) if the work day is longer than 8 h. This is calculated by dividing 400 $\mu g/m^3$ by the total hours worked in a day. The PEL for a 10-h day, therefore, would be 40 $\mu g/m^3$.

Limiting worker exposure is performed by engineering controls, work practices, and use of respirators. When respirators are used, the employee's exposure is considered to be at the level provided by the protection factor of the respirator. Interestingly, the OSHA General Industry Lead Standard, 29 CFR 1910.1025, was more specific in requiring that the monitoring be performed for 7 h, minimum. This wording does not appear in the Construction Industry Lead Standard.

Exposure Assessment

Exposure assessment must be performed to determine worker exposure. The assessment is performed with personal air samplers, which consist of a filter cartridge and pump. The cartridge is placed in the employee's breathing zone and outside any respiratory protection that the employee may be using. At least one sample for each job classification, i.e., blaster, pot-tender, rigger, supervisor, laborer, etc., must be obtained. The sample must also be representative of the worker's regular, daily exposure to lead. This requires monitoring for a full shift, which includes monitoring when the worker is on breaks.

The worker must be protected during the assessment of exposure. These protection requirements include respiratory protection, personal protective clothing and equipment, change areas, hand washing facilities, biological monitoring (blood sampling), and training. The standard requires assuming a certain level of exposure for listed tasks until the monitoring results are available. Respiratory protection consistent with the task must be provided. The assumed exposures for tasks related to bridge painting are:

500 μg/m^3 (10X PEL)	Hand-tool cleaning. Power-tool cleaning with dust collection systems, including localized vacuum shrouds.
2500 μg/m^3 (50X PEL)	Power-tool cleaning without dust collection systems. Cleanup of dry debris from expended abrasives. Abrasive blast enclosure movement and removal.
>2500 μg/m^3 (>50X PEL)	Abrasive blasting. Welding. Cutting. Torch burning.

Table 6 presents data on representative exposure from the preamble to the OSHA Lead in Construction Industry Standard.

Further exposure assessment is required on a schedule that depends on the results of the initial monitoring. Exposure below the action level requires yearly monitoring; below the PEL, but above the action level, requires monitoring every 6 months; and above the PEL requires monitoring every 3 months. Additional monitoring is required when there are changes of equipment processes, controls, or new tasks have been initiated. Other than hand cleaning, it appears that exposure monitoring would have to be performed each calendar quarter as a minimum.

Table 6. Representative TWA (8-h) exposure levels in $\mu g/m^3$ absent engineering controls and respiratory protection by construction activity.[1]

Construction activity key	Number of observations	Minimum value	Maximum value	Arithmetic mean	Standard deviation	Exposure level used to specify controls[2]
Open abrasive blasting	26	1352	58 700	17 315	19 001	23 680
Open abrasive blasting in full containment	13	2188	58 700	26 673	21 502	37 300
Vacuum blasting	4	2	665	169	331	558
Welding, cutting, and burning	90	1	10 320	1230	1897	1564
Hand scraping	6	6	167	45	63	96
Chemical stripping	296	0.4	476	11	35	15
Power tool use	65	1	20 600	735	2794	1314
Misc. enclosure movement	6	13	2100	504	792	1156
Misc. abrasive blasting/repainting	30	4	9580	1147	2441	1904
Misc. steel structure rehabilitation	54	0.2	4100	145	601	282
Spray painting lead-based paints	37	1	460	74	95	101
Spray painting non-lead-based paint	1	26	26	26	---	26
Brush painting non-lead-based paint	13	0.4	6	2	2	3

[1] From preamble to OSHA Construction Industry Lead Standard.

2 Represents the average exposure level that, statistically, would only be exceeded 5 percent of the time the activity was monitored.

Methods of Compliance

According to OSHA, engineering controls, work practice controls, and administrative controls are the preferred methods to reduce worker exposure. Engineering controls consist of items such as using containment with adequate airflow to move the contaminants away from the worker, or using alternate methods to open abrasive blasting, such as vacuum blasting, vacuum power tools, chemical strippers, etc. Work-practice controls consist of techniques such as using wet methods to reduce the spread of dust, or having workers stand upstream of the area being blasted. The highway and painting industries are examining all of these methods, plus others, to determine their effectiveness at reducing lead exposures and emissions. Administrative controls consist of job rotation. Respiratory protection is then used if these controls do not reduce worker exposure to below the PEL.

The standard also requires that a written compliance program be developed and reviewed every 6 months if worker exposure is above the PEL. The compliance program includes a description of each operation in which lead is emitted, air monitoring data documenting this situation, a report of the technologies considered to meet the PEL, a description of engineering and work practice controls to be used to reduce worker exposure, how the program will be implemented, and other relevant information. The written compliance program must be available at the worksite.

Respiratory Protection

Workers exposed to airborne lead above the PEL must be provided with respirators. The use of respirators is intended as a supplement to the engineering and work practices controls. OSHA acknowledges that the construction industry will rely more on the use of respirators than general industry. The standard reference is 29 CFR 1910.134, Respiratory Protection. This regulation requires the following:

- Written standard operating procedure governing the selection and use of respirators must be established.
- Written verification that respirators are selected based on the hazards involved.
- Instruction and training of the worker in the use of the respirator.
- Fit-testing of employees using negative pressure respirators.
- Regular cleaning and disinfection of the respirator.
- Proper storage of respirators in a convenient, clean, and sanitary location, protected against sunlight and physical damage.
- Routine inspection of respirators, including replacement of worn or deteriorated parts.
- Assignment of respirators to employees for their exclusive use.

- Surveillance of workers to ensure that they are wearing the appropriate respirator.
- Regular inspection and evaluation to determine the effectiveness of the program.
- Annual medical examination by a physician of the employee's medical status showing he is able to use the equipment.
- Only NIOSH- or MSHA-certified respiratory protection may be used.

The required respirators for different airborne concentrations are presented in the standard. The respirators most commonly used on painting projects for different concentrations are:

<500 μg/m^3 (10X PEL)	Half-mask, air-purifying respirator with HEPA filters.
<1250 μg/m^3 (25X PEL)	Type CE abrasive-blasting helmet operated in continuous flow mode.
<2500 μg/m^3 (50X PEL)	Tight-fitting, powered air-purifying respirator (PAPR) with HEPA filters.
	Full facepiece, air-purifying respirator with HEPA filters.
<50 000 μg/m^3 (1,000X PEL)	Full facepiece, air-purifying respirator with HEPA filters.
	Half-mask, supplied-air respirator operated in pressure-demand or other positive-pressure mode.
<100 000 μg/m^3 (2,000X PEL)	Type CE abrasive-blasting helmet operated in a positive-pressure mode.

Air-purifying (negative-pressure) respirators require high-efficiency particulate filters (HEPA), which means the filter is 99.97 percent efficient against particles of 0.3 μm or larger. HEPA filters are color-coded purple. While a half-mask, air-purifying respirator with HEPA filters has a 10:1 protection factor, a full facepiece, air-purifying respirator with HEPA filters has a 50:1 protection factor. However, the full facepiece respirator would require a quantitative fit test, as opposed to a qualitative fit test. A PAPR with HEPA filters also is rated a protection factor of 50 and must be supplied to a worker who requests it, provided the PAPR is adequate protection based on exposure.

A controversy has existed over the protection factor of a continuous-flow, type CE blast helmet. Some manufacturers have tested their helmets in accordance with ANSI Z88.2 - 1991, American National Standard Practice for Respiratory Protection, and have listed their helmets as providing a 1,000:1 protection factor. They are assigned a protection factor of 100:1 in the OSHA Asbestos

Standard. OSHA only recognizes a 25:1 protection factor in the Lead in Construction Industry Standard. Indications are that this occurred due to misuse of the helmets in field practices. Exposure monitoring of blasters in containments with adequate ventilation have shown that 1250 $\mu g/m^3$ can be exceeded when the coating contains high levels of lead (see appendix C). Type CE blast helmets that operate in a positive-pressure mode (a relatively new technology) are just appearing on the market. The helmet and control unit are fairly expensive and present other safety and health hazards, such as limited visibility and lack of effective cooling (heat stress).

The standard does allow the use of a combination of respirators. A common occurrence has been the use of a half-mask respirator with HEPA filters inside a continuous-flow, type CE blast helmet. It is not clear, however, if this practice will increase protection factors. An analysis of OSHA past practices indicates that combination of respirators is for different hazards, not to increase the protection factor for one hazard.

Personal air monitoring performed on State inspectors has shown the need for respiratory protection. Levels that exceed the protection factor of air-purifying, half-faced respirators equipped with HEPA filters have been measured in some cases.

Protective Clothing and Equipment

Employers must provide workers with protective clothing and equipment, including coveralls or full-body clothing, gloves, hats, shoes, and face shields or goggles. The standard requires that clean clothes be supplied weekly if the exposure is above the PEL. If exposure to lead is 200 $\mu g/m^3$ or greater, clean clothes must be supplied daily. The contaminated protective clothing must be removed at the end of the shift and not worn home by the worker. The industry standard also requires that containers of contaminated protective clothing to be laundered must be labeled: "Caution: Clothing Contaminated with Lead. Do Not Remove Dust by Blowing or Shaking. Dispose of Lead-Contaminated Wash Water in Accordance with Applicable Local, State, or Federal Regulations."

State highway agencies should be concerned about the protective clothing requirements for two reasons: protection of State employees and possible liability for mishandled clothing by contractors. The intent of the protective clothing requirement is to keep workers from wearing the clothing home, thus contaminating their car and family members, especially children. State employees, such as inspectors, who are exposed to lead dust must be adequately protected. Some highway agencies have written into contracts that the contractor will supply clean coveralls, on a daily basis, for the inspector. Disposable Tyvek® suits are available and are a simple means to provide protection for someone, such as an inspector, who enters the work area for a relatively short period of time.

The need for labeling requirements for the contaminated clothing container should also be considered by transportation agencies. While it is the contractor's responsibility under OSHA to properly clean the clothing, transportation agencies may be named in litigation if the clothing is not properly labeled for laundering. If laundering is done on site, the wash water must be treated to remove the lead to below storm sewer requirements. As the lead is present in small particles and is not soluble in neutral waters, filtering through a 5-μm filter should be sufficient.

Housekeeping

Surfaces must be maintained as free as practical of accumulations of lead. The preferred method is by vacuuming, with vacuums equipped with HEPA filters. Shoveling, dry or wet sweeping, and brushing may be used only where vacuuming methods have been tried and found not to be effective. The use of compressed air is only allowed in conjunction with a ventilation system designed to capture the airborne dust created by the compressed air. Daily cleanup of surface-preparation debris is good practice as it also minimizes the possibility of environmental pollution.

Hygiene Facilities and Practices

The lead found in paints enters the body by inhalation or ingestion. Lead is not absorbed through the skin. Personal hygiene practices have a significant impact on how much lead a person might inhale or ingest. Eating, drinking, use of tobacco products, or applying cosmetics is prohibited in areas where workers are exposed above the PEL. Other hygiene facilities and practices required are change areas, showers, eating facilities, and hand washing facilities.

Clean change areas are required for workers exposed above the PEL. They must have separate storage facilities for protective work clothes and for street clothes, which prevents cross-contamination. Workers may not leave the workplace with any protective clothing or equipment.

Shower facilities must be provided, where feasible, when exposure to lead is above the PEL, and must be used. Portable shower trailers with separated clean rooms and dirty rooms are commercially available. Showering only needs to be done at the end of the work shift.

Eating facilities can be either a trailer or a designated area, but must be as free as practicable from lead contamination and readily accessible. The OSHA Compliance Manual for 1926.62 states that surfaces should be cleaned to the HUD floor standard of 200 $\mu g/ft^2$.(63) Prior to entering the eating facility or area, the worker need not remove their protective clothing and equipment provided that the surface dust has been removed by vacuuming, downdraft booth, or other cleaning method.

Workers are also required to wash their hands and face. The same requirements apply any time the worker eats, drinks, smokes, or applies cosmetics. Showering prior to breaks is not required.

Hand washing facilities must be provided. This can be a sink in the shower trailer or a separate unit. Employees must wash their hands and face at breaks and at the end of the day at project sites where it is not feasible to provide shower facilities. As portable trailer-mounted shower facilities are available, the feasibility of having shower facilities does exist on almost any project where compressors, blast pots, and dust collectors could be used.

Medical Surveillance and Medical Removal

Medical surveillance includes biological monitoring of blood and medical examinations. Biological monitoring consists of analysis of blood samples for lead and zinc protoporphyrin (ZPP). The testing frequency is every 2 months for the first 6 months. As long as the worker's blood lead level is below 40 μg/dL of whole blood, retesting can be performed at 6-month intervals. If a worker's blood lead level goes above 40 μg/dL, the testing frequency remains every 2 months until 2 consecutive analyses indicate a blood lead level below 40 μg/dL. Some contractors are measuring blood lead levels on a more frequent basis, usually once a month. They can identify workers with increasing lead levels and correct work practices before their blood lead levels exceed the point where they must be removed from lead-exposure activities.

A worker with a blood lead level above 50 μg/dL must be removed from work where the exposure is above the action level. The worker cannot return to their former job status until two consecutive tests show a blood lead level below 40 μg/dL. Extensive medical protection requirements are presented in the standard.

ZPP is also analyzed along with the blood lead. Workers may have lead stored in their body from previous exposure. ZPP is supposed to indicate recent exposure to lead. There is no level established for ZPP at the present time.

The employer must make annual medical examination and consultation services available to any worker whose blood lead level exceeded 40 μg/dL or who has symptoms of lead poisoning. The requirements of the medical examination are presented in the Standard.

The aim of all the other requirements in the OSHA standards is to protect people working in a lead environment from medical problems caused by lead being absorbed into the body. Blood lead levels are one way of monitoring how much lead is being retained. Until recently, blood lead levels have rarely been measured in people working in the painting industry. Therefore, baseline information on uptake of lead prior to use of containment systems does not exist.

It behooves a contractor to require medical exams of new employees, including measuring their blood lead level. Many blasters and painters are transient employees. Very little is known about their previous job or jobs. Workers have taken pre-employment physicals and elevated blood lead levels have been found to exceed the 50-μg/dL level.

As it behooves the contractor to determine if a potential employee has elevated blood lead prior to hiring, so it behooves the transportation department to request blood lead test results of workers assigned to a project prior to starting work. As employees cannot sue their employer since medical problems are covered under workers' compensation, there have been incidences where workers have sued the owner. As a minimum, blood lead levels should be requested of all employees prior to appearing on the job site and again when they leave. This can help protect the State from unwarranted or frivolous lawsuits.

Some States have started comprehensive lead-exposed worker evaluation programs. For example, the NIOSH-funded Connecticut Road Industry Surveillance Project (CRISP) is an attempt to monitor all workers in Connecticut by a single source—the Yale University School of Medicine.(64) This seems to be working well, but specific contract language was used in CONNDOT specifications that requires contractors to implement the program.

Training

Workers who are exposed to lead above the action level for as little as 1 day per year must receive annual training. Training must include the hazards of lead, the contents of the standard, the specific nature of the operations that could result in exposure to lead, respiratory protection, medical surveillance and medical removal protection programs, engineering and work practice controls associated with their job assignment, the contents of any compliance program in effect, the ban on using chelating agents to reduce blood lead levels except under the direction of a physician, and their right of access to records.

Signs

The standard requires that warning signs be placed around the work area both for the benefit of the employees working in that area and to warn others of potential hazards. The standard has specific wording for the signs, namely, "Warning, Lead Work Area, Poison, No Smoking or Eating."

Recordkeeping

Employers must establish and maintain accurate records of exposure assessment, medical surveillance, medical removals, and objective data for exemption from requirement for initial monitoring. The recordkeeping requirements presented in table 7 are extensive. Records must be maintained for 30 years, except medical removals, which must be maintained for the duration of the employee's employment.

Observation of Monitoring

The employer must provide affected employees or their designated representatives with an opportunity to observe any exposure monitoring. This includes providing the observer with proper respiratory protection, clothing, and equipment, and requiring the observer to comply with other applicable safety and health procedures. The observers are not allowed to interfere with the monitoring, but are entitled to receive an explanation of the measurement procedures, to observe all steps related to the monitoring, and to record the results obtained or to receive copies of the results when returned by the laboratory.

Impact of OSHA Lead in Construction Industry Standard

The OSHA standard has both technical and economic impact on bridge rehabilitation and maintenance activities. The standard applies to any activity where lead will be disturbed, not just to painting activities. This includes welding, cutting, torch burning, and rivet busting. Even activities as coating removal for steel inspection or for making attachments would be covered under this standard. Therefore, reference to the OSHA lead standard must be included in other bridge rehabilitation, maintenance, or demolition contracts, and protection provided to State highway agency employees involved in maintenance activities on bridges painted with lead-based primers where the coating will be disturbed.

Table 7. OSHA recordkeeping requirements.[1]

Exposure Assessment	Date(s), number, duration, location, and results of each sample taken, including a description of the sampling procedure.
	Description of the sampling and analytical methods used and evidence of their accuracy.
	Type of respirators worn.
	Name, social security number, and job classification of the employee monitored and of all other employees whose exposure the measurement is intended to represent.
	Environmental variables that could affect the measurement of employee exposure.
Medical Surveillance	Name, social security number, and description of the duties of the employee.
	Copy of the physician's written opinions.
	Results of any airborne exposure monitoring on or for that employee and provided to the physician.
	Any medical complaints related to exposure to lead.
	A copy of the medical examination results, including medical and work history.[2]
	Description of laboratory procedures and a copy of any standards or guidelines used to interpret the test results or references.[2]
	A copy of the results of biological monitoring (blood lead and ZPP).[2]
Medical Removals	Name and social security number of the employee.
	Date of removal from current exposure to lead and corresponding date that the employee was returned to his/her former job status for each occasion.
	Brief explanation of how each removal is (or was) being accomplished.
	Statement with respect to each removal indication whether or not the reason for the removal was an elevated blood lead level.
Data for Exemption from Initial Monitoring	Information demonstrating that a particular product, material, process, or activity cannot release lead dust or fumes above the action level under any expected condition of use.
	Industry-wide data is acceptable, provided it was obtained under workplace conditions closely resembling current operations.

[1] For OSHA Lead in Construction Industry Standard (29 CFR 1926.62).

[2] Employer shall maintain these records or ensure that the physician maintains these records.

A major impact of this regulation is the requirement to institute engineering and work practice controls to reduce worker exposure to or below the PEL. In the preamble to the standard, OSHA states that they were unable to show that exposure at or below the PEL can be achieved solely by engineering and work practice controls in most operations most of the time.(25) The major engineering control for dry abrasive blasting is ventilation. Therefore, containment that includes a ventilation system will be required on projects where open abrasive blasting is performed. Note that even though alternative methods of surface preparation may be feasible in reducing worker exposure, if the technical requirement of the work is to prepare the surface to SSPC-SP10, Near-White Metal, then suitable methods to achieve the end result must be used.

The action level of 30 $\mu g/m^3$, and PEL of 50 $\mu g/m^3$, is very low and it is not difficult to exceed these limits when performing surface preparation on coating systems with lead-based primers. The US Navy measured worker exposure during a ship overhaul. (27) They reported that exposure to workers who only performed surface preparation with chipping hammers did not exceed the action level with up to 6 percent lead in the coating, while workers performing sanding exceeded the PEL with as little as 0.2 percent lead in the coating. Therefore, the probability of exceeding the PEL when performing surface preparation on lead-based primers would appear to be very high, no matter what surface preparation method is used. Table 6 presents exposure data for common activities and surface preparation methods used on bridge painting or bridge rehabilitation, as reported in the preamble to the OSHA Lead in Construction Industry Standard.

A major impact of the regulation will be cost. OSHA estimates the total annual recurring cost of achieving compliance to be in the range of $365 million to $445 million, with an additional one-time start-up cost during the first year of $150 million to $183 million for worker training, biological monitoring, medical examinations, and medical removal benefits.(26) The estimate for the total annual recurring cost for highway and railroad bridge painting is $56,742,000, which they estimate to be 13.99 percent of the total project cost. Appleman estimates that $100 million/yr is spent by State highway agencies on bridge painting, which translates to an extra $14 million needed to comply with the OSHA regulation.(2)

OSHA also estimates the annual recurring compliance cost per worker to be $775 for painting contractors; $3,398 for highway and street contractors; and $3,625 for bridge, tunnel, and elevated highway contractors. Lyras indicates that these estimates may be low, and if the contractor must purchase both personal equipment and major equipment and drastically change work practices, then the cost may be in excess of $20,000 per worker (depending on the size of the firm).(28)

III. CONTAINMENT

The purpose of containment is to prevent or minimize the debris generated during surface preparation from entering into the environment (soil, air, or water) and to facilitate the controlled collection of the debris for disposal. The level and type of containment needed is dependent on the surface preparation method used. In addition, containment must be designed to reduce the workers' exposure to lead.

Containment can be as simple as ground tarps or as complex as highly structured units with negative-pressure ventilation systems. Steel Structures Painting Council (SSPC) Guide 6I (CON) presents information to assist in specifying containment requirements. The SSPC Guide describes containment by the containment enclosure components and ventilation system components.

The containment components include:

- Containment materials (rigid or flexible).
- Air permeability of containment materials (air impermeable or air permeable).
- Support structure (rigid, flexible, or minimum).
- Joint (fully sealed or partially sealed).
- Entryways (fully sealed with airlock, overlapping door tarps, or open seam).
- Air make-up points (controlled or open).

The containment materials are either rigid (such as plywood, metal, and plastic or similar materials) or flexible (such as tarps, screens, drapes, and plastic sheeting). It is very difficult to construct a containment on a bridge solely of rigid materials, as connections to the structure will be required.

Air permeability of the containment material refers to dust and wind. Rigid materials are air impermeable. Tarps, drapes, and plastic sheeting are examples of air-impermeable, flexible materials. Air-permeable, flexible materials are formed or woven panels that allow air to flow through them, but will retain some of the airborne particulates. Screen materials fall into this category. They are defined by the amount of light transmittance that is blocked by the screen. For example, a 95-percent screen blocks 95 percent of the light. This does not mean that 95 percent of the debris or dust particles will be retained by the material. Also, while some wind does pass through the screen at low air velocities that reduce wind load, above 16.1 to 24 km/h (10 to 15 mi/h) the screens are equivalent to solid tarps.

The support structure is either rigid, flexible, or minimal. Rigid support structure are comprised of scaffolding, pipe staging, or solid framing, which does not allow movement of the support structure. The containment materials are attached to the support structure. Flexible support structures include cables, chains, wires, etc., which allow some movement. Flexible support structures must be properly designed to prevent tarps from ripping in high winds. They should be positioned at regular intervals so that high winds are encountered, the support structure picks up part of the wind load. Minimal support structure involves no support other than the attachments to the structure and perhaps to the ground or containment floor.

The joints are either fully sealed or partially sealed. Fully sealed joints require a complete mating of joints between containment materials, and between the structure and the containment materials. There are a number of methods of sealing joints, such as overlapping and securing tarps, taping, caulking, or use of foams, weatherstripping rubber, etc. The choice of sealing materials depends on the surfaces to be mated. Partially sealed joints involve joining materials together without a complete seal.

Entryways to the containment can be either an airlock, overlapping tarps, or open seam. An airlock is a fully sealed entryway with two doors that can be sealed and an intermediate area. One door is not opened until the other door is closed. This arrangement greatly minimizes air losses through the entryway. Overlapping door tarps involve the use of multiple flaps to minimize the amount of dust that can escape. Open seams allow entering and exiting through unsealed seams in the containment material.

Make-up air points can be either controlled or open. Controlled make-up air points refer to the use of baffles, louvers, flap seals, filters, ducts, etc. so that dust and debris does not escape from these points. Open-air make-up points refer to openings between containment panels or openings put into the containment that do not have protective devices or features. Allowing for adequate make-up air on containments with ventilation systems is a critical feature, which is discussed more fully below.

The ventilation system components include:

- Input airflow (forced or natural).
- Air pressure inside containment (instrument verification, visual verification, or not required).
- Air movement inside containment (minimum air movement specified or not specified).
- Exit airflow/dust collection (air filtration required or not required).

Input airflow can be either forced or natural. Forced input airflow involves the use of fans or blowers at air entry points. Input airflow by this method must be properly balanced with the exhaust air capacity so the containment remains under negative pressure. Proper design is also important so that dust and debris is not blown out through nearby openings and that dead spots are not created. Natural airflow consists of the draft created by dust collection equipment. The air make-up points are open and do not have fans or blowers pumping air into containment.

Air pressure inside containment is important, especially with high dusting methods such as abrasive blasting, where negative pressure is required to minimize the escape of dust. Instrument verification of negative pressure involves measuring the pressure inside containment with a magnehelic gauge. A length of plastic tubing is attached to one of the ports of the gauge and placed inside containment. The other port on the gauge is left open to the atmosphere outside containment. An average minimum negative pressure inside containment of 0.8 mm (0.03 in) water column is currently recommended. Visual verification of negative pressure involves examining the containment from all sides to see if the walls are being sucked inward. This method can be used if the containment is constructed of tarps or other flexible materials. Visual verification can also be performed by use of a smoke bomb or other visible means that is set off inside containment. The smoke should not escape through seams, joints, etc. This method is more appropriate for containments constructed of rigid materials, and can also be used on containments constructed of flexible materials. Containments without dust collection equipment do not require negative pressure.

Air movement inside containment either has the minimum air movement specified or not specified. The Industrial Ventilation Handbook recommends a minimum air velocity of 30 m/min (100 ft/min) in a cross-draft direction, and 18 m/min (60 ft/min) in a downdraft direction based on visibility.(65) Higher airflows may be needed if one worker is downstream from another. It must be emphasized that these airflows are based on visibility and not on worker exposure to lead. The containment guide requires the specifier to include the minimum airflow.

The last item is the exit airflow, with air filtration required or not required. When air filtration is required, dust collectors or bag filters are used to collect the fine particulates exiting the containment. When air filtration is not required, there is little control of the debris emitted into the environment.

The components and subcomponents are combined in different manners to describe five classes of containment, with Class 1 being the most stringent (and most costly) and Class 5 being the least stringent (and least expensive). The class of containment needed varies by surface preparation method and potential environmental impact. Thus, dry abrasive blasting that generates a lot of dust would require a high level of containment, while a lower level of containment would be sufficient for hand-tool cleaning. Class 3 is the lowest class of containment requiring a ventilation system. Experience to date indicates that a Class 3 containment system will meet EPA Air Quality Standards provided impermeable containment materials are used. The other requirements for a Class 3 system are: rigid or flexible containment materials; rigid or flexible support structure; fully sealed joint; overlap entryway; controlled or open air make-up; natural or forced-input airflow; visual verification of negative pressure; minimum air movement specified; and air filtration on the exhaust.

SSPC is in the process of revising Guide 6I(CON). Indications are that Classes 1 and 2 will be combined, as the differences between them are small. There will be only four classes of containment, with separate tables defining containment systems for hand- and power-tool cleaning, water blasting, and chemical stripping.

DESIGN OF NEGATIVE-PRESSURE CONTAINMENT SYSTEMS

The engineering design of a negative-pressure containment system requires knowledge of air movement and ventilation principles. Once the theoretical design requirements are known and appreciated, practical containment designs can be developed.

Air Movement

Air must be continuously brought into an enclosure in a manner to keep the particulate and lead levels diluted to such an extent for both visibility and to keep the worker's lead exposure to a safe level. Negative pressure alone does not suffice. There must be adequate air movement in the containment to control the fine particulates.

To understand how to provide adequate dilution air, a review of the basic principles of air movement is necessary. The volume of air moving through an enclosure (Q), the velocity of this air (V) being moved, and the cross-sectional area (A) across the enclosure are interrelated according to the following formula:

$$Q = V \times A$$

where:

Q = quantity of air moved in m^3/min (ft^3/min)
V = velocity of air in m/min (ft/min)
A = cross-sectional area of the enclosure in m^2 (ft^2).

One point to note is that the cross-sectional area is a controlling factor and not the length or volume of the enclosure.

If the velocity of an air stream of 30 m/min (100 ft/min) flows through an enclosure with a cross-sectional area of 9.3 m^2 (100 ft^2), then the quantity of air can be calculated as follows:

$$Q = 30 \text{ m/min } (100 \text{ ft/min}) \times 9.3 \text{ m}^2 \ (100 \text{ ft}^2) = 279 \text{ m}^3\text{/min } (10{,}000 \text{ ft}^3\text{/min})$$

Air can only be moved by allowing it to flow from an area of high pressure to an area of low pressure. Thus, pressure differentials are critical to explain how to control air movement.

There are three types of air pressure measurements. These are:

- Velocity Pressure.
- Static Pressure.
- Total Pressure.

Velocity pressure (VP) is the force air exerts upon anything in the path of flow. For example, VP is the force felt on your hand when it is placed in front of a blowing fan. VP is a direct function of air movement (V) and can be described by the following formula:

$$V = 4005\,(VP)^{1/2}$$

where:

V = velocity of air is measured in ft/min, and
VP = velocity pressure of air is measured in inches of water column (WC).

VP will be zero if the air is not moving. However, VP can never be a negative value.

Air inside an enclosure will exert another force that will be perpendicular to all surfaces regardless of whether or not the air is actually moving. This force is called the Static Pressure (SP). Since SP is not a function of air movement, it is independent of VP. Furthermore, if SP is less than the ambient pressure outside the enclosure, then the enclosure is referred to as being operated under negative pressure. The converse is that a positive value of SP would indicate that the enclosure would be operating under a positive pressure relative to atmospheric conditions.

Total Pressure (TP) is nothing more than the algebraic sum of VP and SP. The importance of this term lies in the fact that to provide sufficient dilution in an enclosure, enough horsepower must be available for the ventilation fans or blowers to provide the necessary TP to accelerate air from zero velocity, overcome all of the pressure losses and turbulence in the ducts, elbows, and fittings, and finally pull the air through the filters.

Forced Draft vs. Induced Draft

There are two methods of moving air through an enclosure. The first is forced draft, which relies on the fan or blower forcing a draft into the enclosure. The other is induced draft, where the fan or blower pulls air out of the enclosure.

Forced air draft systems have been commonly used to provide ventilation for ship compartments, water tanks, and other similar containers. However, forced draft systems cause the interior of the tank to be maintained at positive pressure with respect to the ambient air environment. Tanks are, by necessity, airtight except at permanent hatches and vents. On the other hand, a temporary enclosure encompassing a portion of a bridge is usually constructed entirely with tarps or similar soft, flexible materials. Therefore, there are many holes, seams, access panels, etc. that provide numerous leakage points if the enclosure was maintained under positive pressure. Fans and blowers have been used on bridge enclosures as either entry air or for localized air movement near the blasters. The use of fans or blowers with "soft" enclosures is always in conjunction with induced draft.

A negative pressure relative to the outside environment is maintained by continually pulling air out of the enclosure. Thus, most "soft" or temporary enclosures rely upon induced draft systems. The negative-pressure environment permits air to leak continuously into the structure causing dust and particulate to flow against the stream of incoming fresh air. It follows that maintaining an enclosure under negative pressure during abrasive blasting operations will correspondingly satisfy environmental air quality regulations. Small leakages of air at seams, pass-throughs, and other compromises to the "airtightness" of the enclosure are of minor or insignificant concern if the system is designed correctly.

COMPONENTS OF A NEGATIVE-PRESSURE SYSTEM

The basic components of a blasting enclosure can be broken down into the following components:

- Air Entrance.
- Enclosure Structure.
- Ventilation Duct(s).

- Dust Collector(s).
- Ventilation Fans.

A major concern in proper design is minimizing pressure losses. Energy is consumed every time a flow of air changes direction, speed, or is forced against a resistance. The only energy source acting to move the air is the induced-draft fan creating pressure changes. It follows that every change in air direction or velocity, or increase in resistance, causes pressure losses across the entire enclosure system. As the pressure drop increases, the quantity of air moved and the corresponding velocity through the enclosure will decrease.

Pressure drops are a critical design parameter in the fabrication, assembly, and operation of an enclosure with a ventilation system. For example, a typical dust collector may be rated at a certain maximum airflow (Q) at a specified SP. If the pressure losses in the system exceed the SP, airflow will decrease.

Air Entrance

An air entrance (make-up air entry) is needed to allow proper airflow through the enclosure. The air entrance should be positioned such that the air flows through the work area cleaning the dust away from the workers. To date, many of the enclosures seen have not had adequately sized air entrances. It has been the thought of those who constructed enclosures that air would enter containment through seams, entry flaps, connections, and other leakage areas. However, large pressure drops result from forcing input air through such small openings. There is sufficient negative pressure, but the dust will hang in the air inside the enclosure as airflow is reduced. Air entrances were one factor evaluated in this research and are discussed later in this section.

The preferred air make-up entryway would be an open-face entry for airflow considerations. There is nothing to restrict the airflow, so no pressure drops result. An open-face entry is the poorest design from a practical viewpoint. Airflows of only a few miles per hour are needed for ventilation purposes. Air/abrasive blasting is performed with a nozzle where the air/abrasive is traveling at transonic speed, i.e., several hundred miles per hour. Therefore, the airflow coming through the enclosure from the induced-draft system would not be sufficient to control dust blown in the direction of the open-face entry from a blast nozzle. Therefore, controlled air make-up entryways are preferred to deflect high-energy abrasive particles and dust from escaping against the countercurrent of incoming air.

An alternate method to an open-air entry that greatly reduces the entrance-pressure losses is to direct air into the enclosure with a fan. The fan must be rated at a lower capacity than the dust collector. If the entry fan is oversized, then the enclosure will be under positive pressure rather than negative pressure, and dust will be expelled through seams, gaps, and other openings.

Enclosure Structure

The basic design consideration for the enclosure is its size, or more specifically, the cross-sectional area. Current ventilation guidelines indicate a velocity of 15 m/min (50 ft/min) is recommended for steel abrasives, 30 m/min (100 ft/min) for expendable abrasives, and higher velocities if there is someone working downstream from another blaster. These guidelines are based on visibility considerations and not worker exposure to lead. The cross-sectional area and dust-collector capacity must be matched. In the example given earlier, a cross-sectional area of 9.3 m^2 (100 ft^2) required a 279-m^3/min (10,000-ft^3/min) dust collector to maintain an airflow of 30 m/min (100 ft/min). Portable dust collectors range up to approximately 90 m^3/min (30,000 ft^3/min).

On large bridges, such as truss structures or girder bridges high in the air where the air can be moved in a downdraft direction, air velocity requirements would be lower. The guidance provided by the Industrial Ventilation Handbook for visibility purposes is based on floor area, and is 28 m/min (90 ft/min) for 0 to 9.3 m^2 (0 to 100 ft^2), 21.5 m/min (70 ft/min) for 9.3 to 18.5 m^2 (100 to 200 ft^2) and 18.5 m/min (60 ft/min) for 18.5 to 37 m^2 (200 to 400 ft^2). Ventilation systems operated in the downdraft direction on bridges are usually attached to enclosures that have a floor area larger than 37 m^2 (400 ft^2). Lower air velocities may be acceptable, though guidance is not presented in the Ventilation Handbook.

Measurement of airflow inside a containment can be performed using either an anemometer or with smoke bombs. Either a hot wire or vane anemometer can be used, though both types of instruments will indicate air velocity only, and not direction. Smoke bombs will indicate direction (and uniformity) of air movement; velocity can be estimated by timing how long it takes the smoke to cover a premeasured distance.

It is important to remember that the critical place for airflow is in the vicinity of where work is being performed. On a large enclosure, the cross-sectional area can be reduced by using screens, tarps, plastic, plywood, or similar materials. Consideration must be given as to how air will be moved into the work area and how it will be moved out. Forced-air input can be used to create an effective curtain of clean air flowing past the worker. Thought must also be given to the placement of the dust collector duct(s). As an example, take the situation of total enclosure of the end span of a girder bridge with a sloped ground so that the configuration of the enclosure roughly approximates a triangle. While the simplest method is to park the dust collector near the shoulder of the road and draw the air out the bottom, this is the most inefficient configuration. The dust collector should be placed at the end of the bridge, with the air exit placed between the beams. The air openings should be located between the beams at the first span. In this way, the air will move between the beams where the blasters are working.

While properly designed enclosures should be effective at minimizing dust emissions, air flow cannot overcome the force of a blast nozzle. Some dust will escape, especially when work is performed near a seam or opening. A more practical solution is to require enclosure walls to be a minimum of 1.8 m (6 ft) from any steel to be blast-cleaned. This will give sufficient room for the blaster to reach all the surfaces, minimize damage to the sidewall material from direct blasts, and allow the blaster to point away from the enclosure material when doing the majority of the work.

Ventilation Ducts

One of the most critical considerations in the design of a negative-pressure enclosure is the ducting from the containment to the dust collector. There are two important parameters—air velocity in the duct and pressure drop. The minimum air velocities for keeping the dust suspended is 1075 m/min (3,500 ft/min) for horizontal ducts and 1385 m/min (4,500 ft/min) for vertical ducts. Duct length, diameter, and bends in the duct significantly affect pressure drops in the system. The smaller the diameter of the duct, the greater the air velocity is inside that duct, but the greater the pressure drop, also. Pressure drops from friction in the ducts are one of the greatest pressure losses encountered in containment systems. Table 8 presents information on air velocity and pressure drops for different diameters of smooth, galvanized duct for various size dust collectors.

Being able to use straight runs on a bridge is not always possible, especially when the only practical placement of the dust collector is on the bridge deck. Each bend in a duct adds to the pressure drop. As a rule of thumb, a right-angle bend in a duct is like adding another 18 m (60 ft) of hose. To minimize pressure drops from ducts, it is important to use the largest diameter ducts that maintain the proper transport velocity for the dust, keep all ducts as straight and short as possible, and attempt to keep all turns at a minimum radius of two duct diameters.

Airflow within ducts can be measured with a pitot tube. The pitot tube is inserted into the duct and the velocity pressure is measured with a manometer. Air velocity can be calculated from the velocity pressure (VP). Airflow may not be uniform through the duct, so a 10-point traverse is performed to obtain an average. Whenever possible, the traverse should be made 7.5 duct diameters or more downstream from any major air disturbance, such as a bend. The usual method is to make two traverses through the duct at right angles to each other. The spacings of the 10 points is dependent on the duct diameter. The Industrial Ventilation Handbook presents the proper spacings, as well as tables to convert VP to air velocity.(65) Measuring airflows in the duct will determine if the dust collector is running at its rated capacity. Significant reduction in actual airflow versus rated airflow indicates a design deficiency with the ventilation system. A practical guide to measuring duct velocities is contained in appendix F.

Dust Collectors

There is a pressure drop associated with moving air through the filters that are designed to remove the particulates from the air. This pressure drop is usually a few inches of water column. The pressure drop increases as the filter cake builds up. Dust collectors are equipped with devices such as reverse, pulsating air jets to dislodge the majority of the filter cake during normal operation. Commercially available dust collectors have a magnehelic gauge to measure the pressure drop across the filters. Proper operation of the dust collector should include regular observation of this gauge to determine if the pressure drop is within the manufacturer's specified range. The pressure drop associated with the dust collector must be considered in the overall design of the ventilation system.

Table 8. Friction losses for varying duct diameter for 30 m (100 ft) of straight duct.

Dust Collector	Diameter of Round Duct cm (in)	Velocity m/min (ft/min)	Pressure Drop in Water Column mm (in)
5,000 cfm	20.3 (8)	4359 (14,300)	88.9 (35.0)
	25.4 (10)	2774 (9,100)	27.9 (11.0)
	30.5 (12)	1951 (6,400)	11.7 (4.6)
	35.6 (14)	1433 (4,700)	5.1 (2.0)
	45.7 (18)	869 (2,850)	1.4 (0.55)
	61.0 (24)	488 (1,600)	0.33 (0.13)
	76.2 (30)	320 (1,050)	0.11 (0.042)
	91.4 (36)	216 (710)	0.04 (0.017)
10,000 cfm	25.4 (10)	5578 (18,300)	88.9 (35.0)
	30.5 (12)	3871 (12,700)	45.7 (18.0)
	35.6 (14)	2896 (9,500)	20.3 (8.0)
	45.7 (18)	1737 (5,700)	5.6 (2.2)
	61.0 (24)	975 (3,200)	1.2 (0.5)
	76.2 (30)	625 (2,050)	0.41 (0.16)
	91.4 (36)	433 (1,420)	0.17 (0.065)
20,000 cfm	30.5 (12)	6100 (>20,000)	>255 (>100.0)
	35.6 (14)	6035 (19,800)	71.1 (28.0)
	45.7 (18)	3444 (11,300)	20.3 (8.0)
	61.0 (24)	1951 (6,400)	4.8 (1.9)
	76.2 (30)	1281 (4,200)	1.6 (0.62)
	91.4 (36)	869 (2,850)	0.61 (0.24)

Ventilation Fans

The air movement again imparts a restriction to the flow by a pressure loss as the air velocity is reduced to zero when exiting the fan or blower. Note that any rapid turn immediately after the discharge from the fan can have a considerable pressure drop as a result of high velocity of the air at this point. Thus, a short stack will significantly minimize, if not eliminate, this problem. The exit stack is part of the construction of the dust collector. Very little can be done, short of redesigning the unit, if there is a significant pressure drop from the exiting air.

EVALUATION OF CONTAINMENT AND VENTILATION SYSTEMS

Field Studies

Initially, the research plan included field evaluations of containment systems to determine their effectiveness and to develop a classification system to compare systems in relationship to each other and their overall efficiencies. Two projects were evaluated (one other was attempted, but proved to be futile). Appendix D presents the information obtained from these evaluations. While these field evaluations were useful in documenting conditions, the results were of limited value due to inability of the research team to make changes in containment design to study different variables. It should be noted that these field evaluations were performed between September 1990 and March 1991, and significant improvements have occurred since that time.

Some valuable information was gleaned from the field studies. Worker exposures to lead can be quite high. Poor personal hygiene practices were found to be a major cause of worker exposure. Smoking, eating, and drinking in areas near the containment were noted. This practice would not be allowed today. Monitors close to the dust collectors had higher values, in general, for lead emission than other areas outside containment. Surfaces were found to have significant quantities of lead. For example, table 8 presents the results of surface wipe tests on various surfaces comparing 1991 practices to 1993 practices. OSHA has indicated that they will require surfaces to be cleaned to below the 200-μg/ft^2 requirements of the OSHA Lead in Construction Industry standard.(63)

It is worth emphasizing, at this point, the vast changes that have occurred in the short timeframe since the beginning of the decade. The painting industry was just becoming aware of the hazards of lead at the beginning of the decade. The proceedings of the SSPC Lead Paint Removal Symposia between 1988 and 1990 contained only one full article on the occupational health hazards of lead. In the early 1990's, as the use of full containment was being used more and more, the industry became aware that some workers were being poisoned. Prior to that time, it was rare that the blood lead level in a worker was measured. Also at that time, the painting industry was just becoming aware of the OSHA General Industry Standard for Lead (29 CFR 1910.1025). Contractors who rigorously followed the requirements in the General Industry Standard and enforced these requirements found that blood lead levels in workers were held constant or were decreased. The article on the 1993 project (reference 66) cited in table 9 reported that average blood lead level of blasters was 15 μg/dL for the first 4 months of the project, with no significant increase in any blaster over the 4-month period. This is quite a change from 1991.

Table 9. Lead on surfaces ($\mu g/ft^2$).

Location	1991 Project	1993 Project[1]	
		Pre-Clean	Post-Clean
Decon trailer, dirty side wall	438		
Decon trailer, dirty side floor	20,295		
Decon trailer, clean side wall	37		
Decon trailer, clean side floor	7,644		
Worker change area, wall	249		
Worker change area, floor	70,020		
Decon trailer, dirty room		822	63
Decon trailer, shower room		203	78
Decon trailer, clean room		219	21
Lunch table		221	18
Food cooler		180	7
Workers' hands		642	47

[1] Reference 66.

Two circumstances occurred during the research that resulted in changes to the work plan. One was the publication of the SSPC Containment Guide. This guide provided a classification system. Therefore, the need to develop one was diminished. However, the information presented in the Containment Guide was known to originate from industry experience, with limited or no documented tests to substantiate some of the information. The other fortuitous circumstance was the availability of an old highway bridge from a bridge construction company. The multi-span girder bridge was dismantled and erected on the property of the research team. This allowed planned tests to be performed under controlled conditions. Therefore, this portion of the research was altered to evaluate the requirements in the Containment Guide and to study the design of negative-pressure containment systems. The results of the research on the containment structure are presented below. The ventilation system is discussed later.

Containment Materials

There is a wide range of containment materials available. As with most products, there is also a wide range of quality and cost. If even the lowest cost and poorest quality materials performed adequately, there would be no need to develop performance criteria for containment materials.

Some materials are definitely not suitable to contain lead dust generated during a blasting operation.

There are two characteristics that are important from the State highway agency perspective—durability and lead permeability. To evaluate these characteristics, tests were developed that simulated typical enclosures. Based on these evaluations, summarized in table 10 and contained in appendix E, minimal requirements for containment materials were established. These are:

- Screens (air permeable) are not suitable for abrasive-blasting containment.
- Screens may be suitable for containment of operations other than abrasive blasting, e.g., power-tool cleaning, vacuum blasting, and spray painting.
- Woven materials are permeable if uncoated. However, even coated, woven materials deteriorate with use.
- Materials should be sufficiently durable to withstand a 4-s blast from the blast hose at a distance of 1.2 m (4 ft).
- Materials other than rubber should be kept a minimum of 1.5 m (5 ft) from blasting operations.
- Some materials can change with use.

If these guidelines are followed, containments constructed of fabrics meeting the minimal requirements will be much more durable and effective.

Table 10. Containment materials tests for durability and permeability.

Materials	Time to Perforation (seconds)		Lead Permeability ($\mu g/m^3$)
	1.2 m (4 ft)	1.5 m (5 ft)	
Screens	3	10	2000-3000
Reinforced Polyethylene	5	16	BDL[1]
Reinforced Vinyl	11	98	BDL[1]
Reinforced Rubber	> 150	NT[2]	BDL[1]
Coated Woven Polypropylene	4	13	New: BDL[1] Used: 325
Uncoated Woven Polypropylene	4	11	825

[1] Below Detectable Limits of 75 $\mu g/m^3$.

[2] Not Tested.

Joints

A number of seaming methods were tested. The test method and seams tested are described in appendix E. Table 11 summarizes the lead permeability results. All materials used in seaming tests had previously been tested for permeability and were found to produce results below the detectable limit of 75 $\mu g/m^3$. The best tarps are only as effective as the seams and the seal against the structure. Often in the past, tarps were joined by simple butt seams. The testing revealed that a 25-mm (1-in) tear in a tarp gave measurable releases of lead. This indicated that butt seams would be inadequate. During the testing it was obvious that single taping, or even double taping, of seams was also inadequate. Dust collected on the tape and quickly rendered it useless. It was also apparent that seams must be strong. The material had to be taut to the test frame to seal. Weak seams could not even be tested. The same problem would occur in field use.

The following seaming and sealing guidelines were developed based on the work performed.

- Seams must be sealed and must be as strong as the fabric itself.
- Butt seams are not suitable for abrasive-blasting operations.
- If tapes are used, the material must be thoroughly cleaned in the area of the tape applications.
- Seals against the structure should be continuous.
- Small cracks and openings should be sealed.

Table 11. Permeability of seaming methods.

Seam Type	Lead Permeability $\mu g/m^3$
Rolled and Clamped	BDL[1]
Double-Laced and Taped	100
Caulked and Taped	91
51-mm- (2-in-) wide Velcro	1,417.00
25-mm (1-in) Tear	280

[1] Below Detectable Limits

Some of the best seam and seal designs were found to be:

1. <u>A rolled and clamped seam.</u> (Figure 1)
   An additional line of reinforced grommets is sewn 0.30 m (1 ft) from each edge. The tarps are fastened together at the 0.3-m (1-ft) reinforced area. This leaves 0.3 m (1 ft) of each tarp as excess. This excess is rolled and clamped with spring-loaded clamps. If tarps must be seamed in place, this technique worked well.

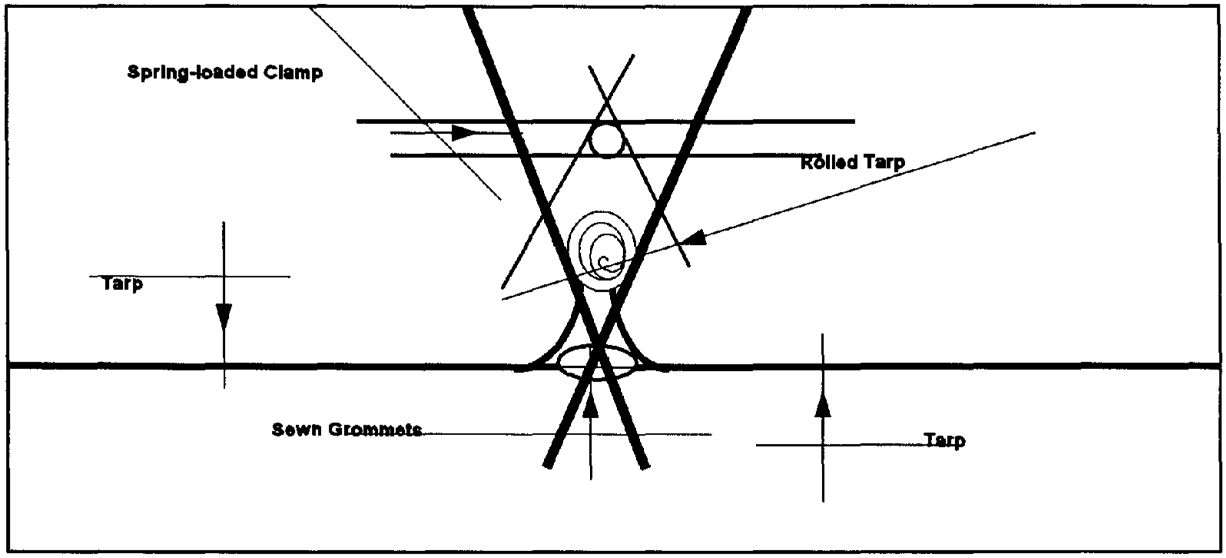

Figure 1. Rolled and clamped seam.

2. <u>Double-Laced Seam.</u> (Figure 2)
   An additional line of reinforced grommets is sewn 0.3 m (1 ft) from each edge. The tarps are fastened together with a 0.3-m (1-ft) overlap. The seam should be taped. The seam works well if the tarps are to remain seamed for long periods of time and if the seam can be made on the ground prior to installation on the structure. Rope diameter should be within 1.59 mm (1/16 in) of grommet hole diameter. Tapes can be used for added protection.

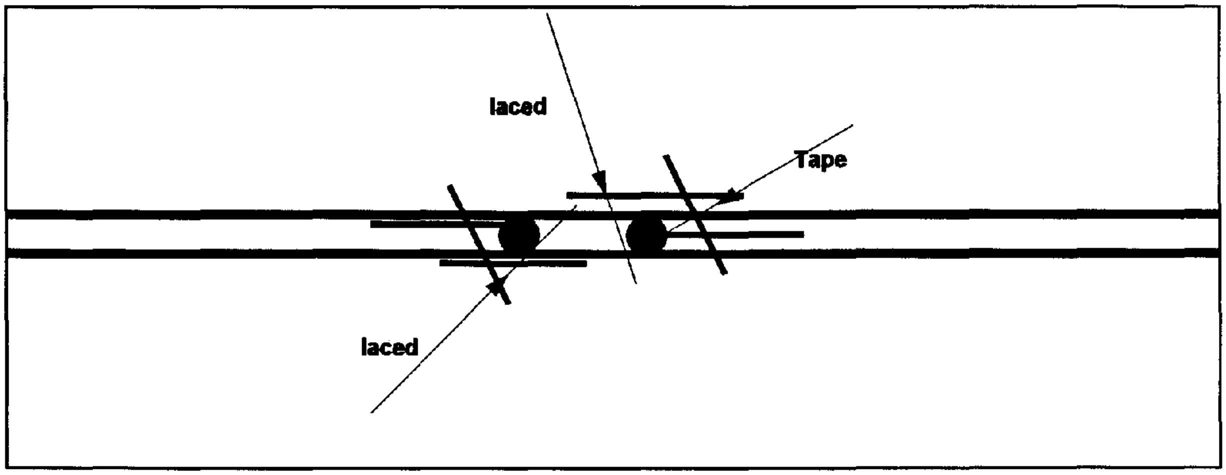

Figure 2. Double-laced seam.

3. Caulked and Taped Seam. (Figure 3)
Solid vinyl and reinforced polyethylene or polypropylene are suitable for this method. However, the seams must not be used for support of the tarp. The seam consists of a two-sided tape or caulk in the overlap and the edges are sealed with tape. Since the technique requires simultaneous pressure on both sides of the tarp, either it must be done on the ground or it becomes a two-person operation when the tarps are in place.

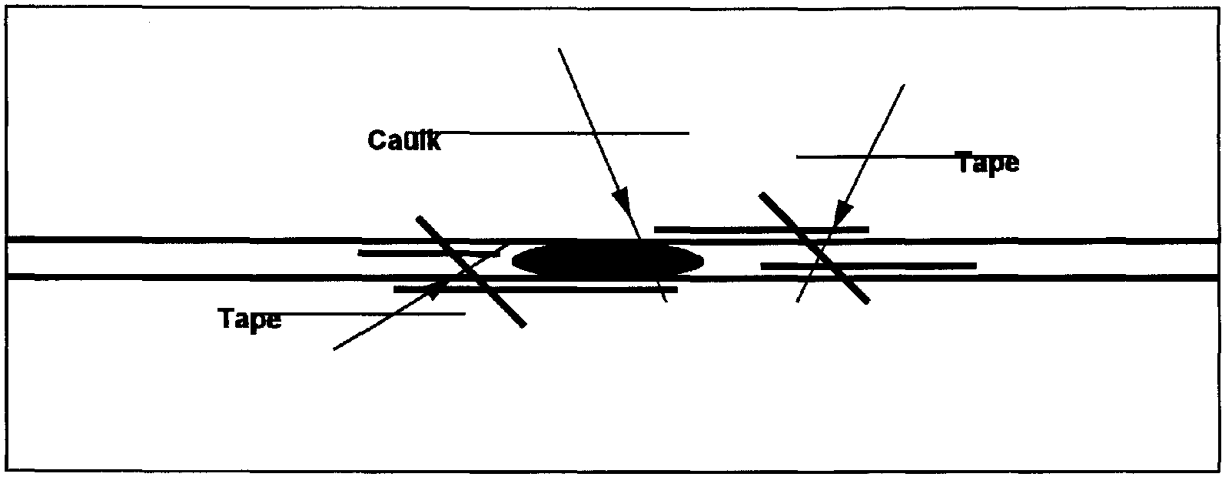

Figure 3. Caulked, taped seam.

Small holes release lead. Testing clearly indicated that even 25.4- or 50.8-mm (1- or 2-in) tears in the fabric or coated woven fabric that are excessively worn release significant amounts of lead. Tarps that can lose their impermeability (coated woven fabrics) should not be used longer than 6 months. (Further testing is necessary to better determine if 6 months is too stringent or too lax.) These types of tarps should be dated during initial installation and checked for permeability on a regular basis. There have been improvements in tarp-coating technology that were not available when the tests were conducted. Holes should be repaired. It is recommended that holes greater than 160 cm^2 (25 in^2) must be repaired immediately as well as rips or tears greater than 30 cm (12 in) in length. Smaller holes or tears should be repaired as soon as practical, typically after blasting operations are finished for the day, but prior to resuming blasting operations the following day

VENTILATION SYSTEM

The ventilation of containment is important to minimize releases to the environment and worker exposure to lead. OSHA requires that engineering controls be employed and worker exposure to hazardous materials be lowered to as low as practical prior to using respirators. Ventilation systems will be a required engineering control when performing dry abrasive blasting.

A series of abrasive-blasting containments were designed and evaluated. The designs were all based on moving air in a cross-draft direction. A complete discussion of the testing protocol and results are presented in appendix F. A wide range of variables were studied, including method of removal, containment size and orientation to the structure, ventilation rates, and negative pressures. Obviously, the amount of lead in the paint affects environmental releases and worker exposure. The testing that was performed was all done on paint with a lead concentration of 50 percent by weight in the dry film or greater. Lower total lead concentration should reduce exposure.

Containment Design

Four containment designs were evaluated. These were either parallel or perpendicular to the beams and either 2.13 m (7 ft) or 4.27 m (14 ft) tall. As can be seen in table 11, none of the variables studied had any pronounced effect on worker exposure to lead. Containments designed with ventilation air flowing parallel to the beams rather than perpendicular to the beams would be expected to lower worker exposure to lead as the air would be moving more efficiently past the worker. No discernible difference in worker exposure to lead was found between parallel and perpendicular containments. The magnitude of the flow through containment also did not have a discernible effect on worker exposure to lead over the range examined. It was concluded, therefore, that worker exposure to lead was influenced in great part by the high-speed air exiting the blast nozzle. This high-speed air would appear to be redirected by obstructions, such as flanges and diaphragms, blowing the dust back towards the blaster.

The ventilation system does appear to be effective in reducing worker exposure to lead. OSHA reported an average exposure to lead of 37 300 $\mu g/m^3$ for abrasive blasting (see table 6). The average exposure obtained for all the tests performed for this research was 10 300 $\mu g/m^3$ white blast cleaning a structure known to have 50 percent lead in the existing coating (a very high level).

The results indicated that requiring airflows greater than 31 m/min (100 ft/min) in a cross-flow direction, as recommended for visibility purposes in SSPC Guide 6I (CON), do not have a significant effect on reducing worker exposure to lead. If anything, the data indicated that lower airflows may be possible without a significant increase in the blaster's exposure to lead. Further evaluation at lower airflows are warranted.

Another conclusion drawn from the data was that worker exposures far exceeded the maximum concentration of 1250 $\mu g/m^3$ now allowed by OSHA for use of type CE continuous-flow blast helmets.

Lowering worker exposure levels by engineering controls on the ventilation system would be impossible or impractical, as the exposure level would have to be reduced by a factor of 4 to 10.

Lead exposures were measured inside the blasting helmet concurrently with measurements outside the blasting helmet during some of the blasting tests performed for this study. The data are reported in appendix C. The results showed the protection factor achieved was in the range of 500 to 1,000:1. In no case was the lead concentration inside the blast helmet above the OSHA lead action level of 30 $\mu g/m^3$.

Table 12. Worker exposure vs. containment design.

Containment Design	Containment Height m (ft)	Worker Exposure (μgPb/m^3)	Average Airflow m/min (ft/min)
Parallel with beams	2.2 (7)	4250 - 15 500	61 (200)
Parallel with beams	4.3 (14)	8500 - 19 500	23 (75)
Perpendicular to beams	2.2 (7)	3500 - 15 250	91 (300)
Perpendicular to beams	4.3 (14)	6,000.00	52 (170)

Ventilation

It is important for the highway industry to know how much ventilation is required. The more air that must be moved, the more costly the project. For this reason, considerable effort was placed on studying the components of ventilation and the effects of these components on airflows through containment.

If airflow is to be measured, it must be determined exactly how to measure airflow. There are two methods. The first method is to use an anemometer (air-speed meter) and measure the air movement inside containment (a direct approach). The second method is to measure the airflow through the ducts and divide by the cross-sectional area of the containment (a more indirect approach). Both of these methods were used in a wide assortment of containment configurations. The data in appendix F are summarized in table 13. Note that these tests were performed without any disturbances from a blast nozzle. By comparing the air output of the dust collector, the air volume through the ducts, and the measured air volume through containment, it can be seen that the best correlation between dust collector output and estimated airflow through the containment is achieved by using the duct measurement technique. Direct measurement gave high results—usually significantly greater than the rated capacity of the dust collector. The procedure for measuring air velocity in ducts is presented in appendix G.

Unfortunately, calculating airflow through containment by measuring airflow through exhaust ducts does not give information on the distribution of the airflow. Table 14 presents the results of airflow measurements made with an anemometer. Three measurements each were made in the top, middle, and bottom third at two cross-section locations in each of four containment orientations. The data for each orientation consist of five separate tests where different air input devices were tested. The data show that airflow between the beams in both parallel orientations was about 60 percent of the total average airflow through containment, while the airflow between beams was about 30 percent of the total average airflow through containments constructed perpendicular to the beams. This further substantiated the conclusion that the high-speed air from the blast nozzle was a critical factor in the blaster's exposure to lead.

Table 13. Measured airflow rates in containment.

Containment Type	Height m (ft)	Air Input Method cmm (cfm)	Dust Collector Rated Capacity cmm (cfm)	Measured Air Volume Through Ducts cmm (cfm)	Measured Air Volume Through Containment cmm (cfm)
Parallel	4.3 (14)	Open End	509.7 (18,000)	435.2 (15,369)	723.1 (25,536)
Parallel	4.3 (14)	HSHV Fan[1]	509.7 (18,000)	468.0 (16,528)	934.8 (33,012)
Parallel	4.3 (14)	Baffle[2]	509.7 (18,000)	434.2 (15,334)	991.9 (35,028)
Parallel	4.3 (14)	LSHV Fan[3]	509.7 (18,000)	435.3 (15,373)	832.5 (29,400)
Perpendicular	4.3 (14)	Open End	566.3 (20,000)	523.9 (18,503)	611.1 (21,582)
Perpendicular	4.3 (14)	HSHV Fan	509.7 (18,000)	469.2 (16,568)	1,127.0 (39,798)
Perpendicular	4.3 (14)	Baffle	566.3 (20,000)	470.7 (16,624)	588.7 (20,790)
Perpendicular	4.3 (14)	LSHV Fan	509.7 (18,000)	471.6 (16,655)	715.8 (25,278)
Parallel	2.2 (7)	Open End	509.7 (18,000)	448.2 (15,827)	623.0 (22,000)
Parallel	2.2 (7)	Baffle	509.7 (18,000)	421.0 (14,867)	699.4 (24,700)
Parallel	2.2 (7)	LSHV Fan	509.7 (18,000)	409.7 (14,470)	792.9 (28,000)
Perpendicular	2.2 (7)	Open End	566.3 (20,000)	528.6 (18,669)	573.6 (20,256)
Perpendicular	2.2 (7)	HSHV Fan	566.3 (20,000)	563.2 (19,890)	906.1 (32,000)
Perpendicular	2.2 (7)	Baffle	566.3 (20,000)	558.3 (19,716)	423.2 (14, 944)
Perpendicular	2.2 (7)	LSHV Fan	566.3 (20,000)	563.7 (19,908)	724.9 (25,600)

[1] High-Speed High-Volume Fan.
[2] Plywood Plenum.
[3] Low-Speed High-Volume Fan.

Table 14. Comparison of airflow between beams versus average airflow through containment.[1]

Containment Orientation	Airflow between beams m/min (ft/min)	Average Airflow m/min (ft/min)
Parallel to beams, sides to ground	69 (223)	115 (372)
Parallel to beams, sides to platform	91 (296)	159 (513)
Perpendicular to beams, sides to ground	31 (100)	102 (330)
Perpendicular to beams, sides to platform	43 (138)	151 (489)

[1] Airflow measured with an anemometer.

In addition to measuring airflow through containment with an anemometer, smoke bombs were used so the air movement could be seen. It was found that obstructions, such as diaphragms, had a significant impact on air movement. Eddy currents were observed with the air moving in the opposite direction to the main flow of air. Therefore, some of the velocity measurements made inside containment and used to calculate the air volume moved through containment, as reported in tables 13 and 14, were not indicative of the general airflow, but of specific localized conditions. This observation further confirmed the conclusion that calculating airflows by measuring the volume of air moving through the exhaust ducts was a more accurate method for determining average airflow through containment.

While the research performed on containment design showed that worker exposure to lead was influenced greatly by the high-speed air exiting the blast nozzle, adequate ventilation is needed to lower the blaster's exposure as much as reasonably possible and to facilitate clearing the containment for activities such as cleanup, inspection, etc. The best procedure for evaluating air movement appears to be calculating air velocity by measuring the volume of air being transported through the exit ducts and using a smoke bomb to determine any areas of unusual airflow direction.

Negative Air

Negative air pressure is also an important component of the ventilation system to reduce emissions to the environment. A series of experiments were performed in conjunction with design of air inputs to evaluate negative pressures. In all cases, a 510-m^3/min (18,000-cfm) dust collector was used at full throttle to create the negative pressure. The results are presented in table 15.

A range of negative pressures were achievable. In all cases, negative pressure was verified visually, i.e., concave containment sides, even with negative pressures as low as 0.38 mm (0.015 in) of water column. In one case, with a closed system, the containment imploded when the negative pressure exceeded 33 mm (1.3 in) of water column.

Table 15. Evaluation of negative pressures.

Input Air	Containment Design[1]	Air Pressure mm (in) water	Airflow[5] m/min (ft/min)
Open	A	0.38 (0.015)	87 (280)
	B	0.76 (0.03)	49 (160)
	C	0.76 (0.03)	42 (137)
	D	1.52 (0.06)	102 (331)
Closed	A	31.5 (1.24)	84 (271)
	B	7.1 (0.28)	49 (157)
	C	[2]	
	D	25.4 (1.0)	98 (318)
Baffle	A	7.1 (0.28)	82 (264)
	B	3.3 (0.13)	48 (156)
	C	3.8 (0.15)	42 (136)
	D	7.1 (0.28)	106 (343)
LSHV[3] fan	A	2.5 (0.10)	78 (252)
	B	0.64 (0.025)	45 (146)
	C	2.0 (0.08)	42 (136)
	D	4.8 (0.19)	109 (353)
HSHV[4] fan	A	8.4 (0.33)	87 (283)
	B	2.5 (0.10)	45 (147)
	C	4.1 (0.16)	47 (147)
	D	10.2 (0.40)	109 (353)

[1] Containment designs:
A - parallel to beams with a platform 2.2 m (7 ft) below the deck.
B - perpendicular to the beams with sidewalls extended to the ground.
C - parallel to the beams with sidewalls extended to the ground.
D - perpendicular to the beams with a platform 2.2 m (7 ft) below the deck.

[2] Containment imploded.

[3] LSHV = low-speed, high-volume

[4] HSHV = high-speed, high-volume

[5] Average airflow through containment calculated from measuring airflow in exhaust ducts.

Though high negative pressures were achievable, it was confirmed that a negative pressure of 0.8 mm (0.03 in) water column as recommended in SSPC Guide 6I (CON) could be determined by visual verification. The results of air-monitoring tests for environmental emissions (appendix C) showed that 0.8 mm (0.03 in) negative pressures were sufficient to contain the dust. In all cases where lead and/or particulates were measured on the TSP or PM_{10} monitors, it was noted that visible dust had escaped containment through the baffle air input when the blaster was working near the air input.

Input Air

As stated earlier, the air input must be controlled to ensure that the air is flowing past the worker and to ensure a negative pressure inside containment. Five different methods were evaluated as part of this study. These were:

- Open end - A 3-m^2 (32-ft^2) hole was left in the input end of containment. Air input velocities of 152 to 183 m/min (500 to 600 ft/min) were typical.
- Closed end - No opening provided. Only air inside was that which could leak into containment.
- Baffle or diffuser plenum - A baffle was made of staggered pieces of plywood affixed to each side of dimensional lumber and was placed on the input end. Air input velocities of 305 to 457 m/min (1,000 to 1,500 ft/min) were typical.
- Low-Speed High-Volume (LSHV) Fan - A 914-mm (36-in) fan with a rated delivery of 292 m^3/min (10,300 cfm) in free air. Air leaving the fan had a calculated speed of 444 m/min (1,457 ft/min).
- High-Speed High-Volume (HSHV) Fan - A 508-mm (20-in) fan with a rated delivery of 278 m^3/min (9,800 cfm) in free air. Air leaving the fan had a calculated speed of 1372 m/min (4,500 ft/min).

Based on smoke analysis of air movement in containment, the following observations were made:

- Closed containments provided very poor airflow through containment. The smoke was visible for up to 4 min.
- The open end provided excellent airflow through containment. The visible smoke disappeared in less than 30 s.
- The baffle provided very good airflow through containment. The visible smoke disappeared in less than 1 min.
- The LSHV fan provided excellent airflow through containment. The visible smoke disappeared in less than 10 s.
- The HSHV fan produced very poor airflow. The stream of high-speed air created many pockets of dead air, and the smoke ricocheted off surfaces near the air input.

While the open-end air input was found to provide very uniform airflow, this design would be impractical in a field situation. The simplest of baffles or plenums was found to be effective for uniformity of airflow, but environmental releases of dust were measured when the blaster was working near the baffle. LSHV fans worked extremely well in uniformity and speed of clearing the smoke. HSHV worked very poorly. It was determined that in order to maintain a negative pressure inside containment, the air input area should be no larger than four to six times the area of the exhaust ducts if the exhaust ducts are properly sized to result in 1220-m/min (4,000-ft/min) air velocity in the duct. Another way to size input ducts would be to measure air speed in the input device. The suggested requirement for air input devices is a minimum airflow of 183 m/min (600 ft/min).

Exhaust Ducts

Exhausting the air at the level of the worker or along an entire end of containment is important to achieving good laminar airflow past the worker. Tests were performed on exhaust-duct placements. Ducts were placed in line with the worker, i.e., between the beams and on the ground using the 4.3-m- (14-ft-) tall containment. Those properly placed had a better airflow in the working zone as visually witnessed during the smoke bomb tests. Properly placed exhaust ducts resulted in a 20 percent increase in air past the worker. Good linear airflow is essential for low worker exposures. Linear airflow can only be achieved with well thought out input and exhaust ducts.

Exhaust-duct layout was a major source of reduced airflow for the majority of containment systems examined on bridges. While short, straight runs of duct are the preferred layout, this is difficult to achieve on bridge-painting projects as the dust collector usually must be place on the bridge deck or underneath the structure. The use of flexible ducts with sharp bends alters the shape (cross-sectional area) of the duct, and was found to be the most prevalent deficiency. The recommended design of a bend is a minimum radius of two duct diameters. A simple solution to this problem is to construct bends of a rigid material, such as galvanized tubing, so the bends hold their shape.

During the research on design of containment systems, attention was paid to keeping ducts as straight as possible, with any changes in direction being made as smoothly as possible. A number of duct supports and ramps were constructed using lumber and a nailing gun, with the criterium that construction takes two people no more than 1 h.

Dust Collectors

Dust collectors efficiency, as determined by increased pressure differential across the filters, changed rapidly over the course of the project. It was obvious that only those dust collectors with reverse pulse cleaning mechanisms were effective over the duration of the project. Most dust collectors are now designed in this fashion. Equipment should be monitored to ensure that the filters are not overloaded or collapsed. Typically, there should be a 25.4- to 101.6-mm (1- to 4-in) water pressure drop across the filters. If there is more than a 101.6-mm (4-in) drop, the filters may be plugged; less than 25.4-mm (1-in) drop, a filter may be collapsed. These values may vary and specific minimum and maximum values can be obtained from the manufacturer of the equipment.

Discussions with dust collector manufacturers indicated that the equipment is most efficient when air enters in a laminar fashion. The general recommendation to achieve this requirement is that the duct entering the dust collector be in a straight run for a distance of about 10 duct diameters. Most field operations examined did not meet this requirement. The use of rigid duct would be a simple method to maintain proper flow characteristics into the dust collector.

Dust collectors do emit some lead to the air as the filters are not totally impervious to particulates. To date, there is no known method to monitor lead emissions from dust collectors. Some attempts to measure emissions were made as part of this study, but due to a lack of standardized techniques, all that could be concluded was that measurable lead was emitted.

METHOD OF REMOVAL

Five different methods of surface preparation were evaluated. Two methods involved abrasive blasting—one with expendable abrasive and the other with recyclable steel abrasive. The three alternate methods were: power-tool cleaning, vacuum blasting, and chemical stripping. Results of the tests performed are reported in appendix C.

Abrasive Blasting with Recyclable Abrasives

New steel grit was used as the abrasive. An average production rate of 10.2 m^2/h (110 ft^2/h) was achieved to clean to a Near-White (SSPC-SP10) level of cleanliness. Visibility was very good while blasting, and all surfaces could be cleaned effectively. Worker exposure to lead varied from 4250 to 15 500 $\mu g/m^3$ for the four test blasts performed. As much time was spent vacuuming the debris for recycling as was spent doing the actual blasting.

Abrasive Blasting with Expendable Abrasive

A mineral sand abrasive was used for these tests. An average production rate of 5.9 m^2/h (63 ft^2/h) was achieved to clean to a Near-White (SSPC-SP10) level of cleanliness. Note that a #6 nozzle was used for these tests while a larger #8 nozzle was used with the recyclable abrasive. Therefore, direct comparison of cleaning rates cannot be made. Visibility in the work area was poorer due to the contribution of dust generated from the breakdown of the abrasive. Worker exposure to lead varied from 3500 to 15 500 $\mu g/m^3$ for the five test blasts performed. As much time was spent recovering the debris as was spent blast cleaning.

Power-Tool Cleaning

Power-tool cleaning tests were performed with pneumatic and electric tools. The cleaning rates were very slow and worker fatigue was high. Electric tools were heavy, became too hot to hold without insulating gloves, and overheated. Pneumatic tools achieved an SSPC 11 grade of cleanliness at a production rate of 1.0 m^2/h (11 ft^2/h). It was not possible to clean all surfaces while maintaining the vacuum shroud in its proper orientation. Surface preparation took about twice as long in corners compared to flat surfaces. The debris in the vacuum recovery unit and on the ground cover were weighed and it was found that 2.0 percent of the material was on the ground. The average worker exposure to lead was 107 $\mu g/m^3$, resulting mainly during times when the vacuum shroud was not perfectly sealed to the surface.

Vacuum Blasting

Vacuum blasting was done with both aluminum oxide abrasive and steel grit. Both abrasives had similar average production rates of 1.3 m^2/h (14 ft^2/h) with a rate of 2.3 m^2/h (25 ft^2/h) achieved on flat surfaces. Worker exposures were below the action level for the trials. This is attributed, in part, to the fact that there was no containment and no deck. The trials were conducted for 2.5 h. In this amount of time, operator fatigue was obvious, indicating that productivity would probably decrease as the day progressed. Vacuum blasting required maintaining close contact of the vacuum shroud to the surface. This was difficult or impossible to achieve in restricted areas. Also, it was noted that a slug of abrasive would escape each time the blasting was started or stopped.

Chemical Stripping

Chemical stripping was found to be a viable technique, but would require very careful time management due to the drying times and the application characteristics of the stripper. If production rates are calculated based on the time actually worked, they are between 5.6 to 9.0 m^2/h (60 and 95 ft^2/h). These production rates were for coating removal only. While the technique was found to be suitable for all surfaces, the final product was the original substrate. As most bridges with lead-based paint were not blast-cleaned initially, either blast cleaning would be required or the surface has to be coated with a compatible coating system. In reality, the workers must wait for the material to dry and start removal before it dries too long. Determining the optimum time window for removal requires experimentation. The procedure is further complicated by the fact that the material, when applied to structures that are open to traffic, tends to vibrate from the surface. If downtime is factored in, the rates would be lower.

Worker exposure to lead varied from 123 to 500 $\mu g/m^3$ for the time the tests were performed. This exposure occurred during the cleaning step.

The data collected are summarized in table 16 for typical bridges. Open abrasive blasting was found to be the most productive method. The alternate methods have the advantage of lower probability of environmental releases, hence, less stringent containment needs. All of the methods evaluated would appear to require implementation of the OSHA lead program.

Table 16. Summary of information on removal methods.

Removal Method	Production Rate Typical on Bridges m^2/h (ft^2/h)	Maximum Worker Exposure Expected ($\mu g/m^3$)	Environmental Lead Release Probability
Abrasive Blasting with Recyclable Abrasives	9.3 (100+)	50 000	Low - Moderate
Abrasive Blasting with Disposable Abrasives	9.3 (100+)	50 000	Low - Moderate
Power Tools with Vacuum	0.9-1.4 (10-15)	500	Very Low
Vacuum Blasting	1.4 (15)	500	Very Low
Chemical Stripping	3.7-9.3 (40-100)	500	Very Low

EFFECT OF CONTAINMENT

The design of containment was noted to have an effect on the work performed, especially abrasive blasting. Production rates were slightly higher for containments with a platform compared to containments with the sides draped to the ground. This resulted from being able to move around freely. The blast hose lay on the platform floor and did not have to be supported. With scaffolding in a containment draped to the ground, time was lost adjusting the blast hose when the worker moved. Conversely, worker exposure to lead was generally higher in platform containments. This resulted, in part, from fine particles rebounding off the floor under the influence of the high-speed air exiting the blast nozzle.

IV. WASTE TREATMENT AND STABILIZATION

Historically, the waste regulations were the first of the environmental regulations that were imposed on bridge-painting projects. Abrasive blasting generates relatively large amounts of waste. About 24.4 to 49 kg/m^2 (5 to 10 lb/ft^2) of abrasive are used to prepare the surface. The amount of coating on that surface is only 28 to 85 g (1 to 3 oz). The cost of disposal of hazardous waste is about 5 to 10 times the cost of disposal of non-hazardous waste. Therefore, waste disposal has a significant cost impact on a painting project. There is also long-term responsibility for the waste. Improper waste treatment or disposal may result in future liability for cleanup costs of the disposal site. Therefore, wastes must be properly tested, stabilized, and disposed.

The classification of a waste can only be determined when the waste is generated. The results obtained from the TCLP test used to classify toxic wastes appear to be controlled by the amount of lead, chemical form of lead, and particle size in the sample. Predetermining whether or not a waste will be classified as hazardous can only be performed by obtaining samples using the exact method that will be used during production. This resulted in problems with budgeting painting projects as obtaining pre-samples of debris was costly and required the use of scarce manpower. It also caused problems in bidding on painting projects as anyone who bid the work based on generating a hazardous waste would not be the successful bidder.

Some States responded to the issue by awarding the contract to the lowest bidder based on disposal of non-hazardous waste, and using force accounts if the waste was found to be hazardous once it was generated. This procedure was subsequently found to be unacceptable, as it did not solve the budgeting problem. Also, it resulted in controversy between the State and contractors, as it was possible to bid the work low, but include a high price for hazardous waste disposal with the hopes that the waste will be classified as hazardous.

Three details emerged during the course of the research that had a significant impact on the project: changes in the RCRA regulations, the discovery of abrasive additives to generate a non-hazardous waste, and clarification by U.S. EPA that the State highway agency is classified as the generator of the waste.

In 1990, a modification and clarification of the hazardous waste regulations was published. The Land Ban regulation prohibited the land disposal of hazardous waste. Hazardous waste would have to be treated to below its regulatory limit before being placed in a landfill. The regulation also clarified a confusing section of the hazardous waste regulations pertaining to onsite treatment by the generator. U.S. EPA stated that onsite treatment by the generator during the waste accumulation period was allowed, provided the generator submitted a waste analysis plan prior to treatment. The possibility of onsite stabilization has a significant impact on the cost of bridge painting. A relatively inexpensive stabilization process will result in a non-hazardous waste, which can be disposed at an appropriate landfill that can accept lead-containing, non-hazardous waste as defined by State regulations.

Abrasive additives were a significant finding early in the research project. It was noted that the debris from steel abrasive recycling units rarely was classified as a hazardous waste, though the debris contained a high concentration of lead with a fine particle size, a situation that usually results in high levels of leachable lead.(29) It was hypothesized that the iron in the debris somehow affected the leachable lead concentration. The use of a source of steel (elemental iron) with non-metallic abrasives as slags and mineral sand abrasives is discussed below. A proprietary, cementitious abrasive additive was commercially offered as an abrasive additive during the course of the research. Therefore, effort was directed to the use of abrasive additives.

Also, it became clear early in the research project that the owner of the structure would be considered as the generator of the waste per RCRA.(10) This liability extends indefinitely, including disposal-site cleanup should it be necessary. Therefore, long-term stability of the waste became an important factor.

One of the major, stated goals of RCRA is minimization of waste. This includes not only minimizing the amount of hazardous waste generated, but also waste utilization and recycling. However, the regulations do prohibit dilution and sham recycling. Dilution is a process where a hazardous waste is made non-hazardous by the addition of inert materials, such as adding additional abrasive to surface preparation debris. Sham recycling is use of a waste in a manner which constitutes disposal. The use of surface preparation debris in asphaltic cement concrete was one concept that was judged to be sham recycling. The main argument used by regulators was that the surface preparation debris did not improve the properties of the concrete, and was therefore being added to bypass the hazardous waste regulations. North Carolina DOT does have an agreement with their Department of Natural Resources (DNR) for using blasting debris in asphaltic cement concrete.(30) However, this agreement is specific for the DOT and includes such items as producing the concrete at the State asphalt plants, providing the DNR with a map of the locations where the concrete is used, and agreeing to remediate any site where environmental damage may occur.

The literature and information review did not uncover any accepted uses of lead-containing abrasive blasting debris or paint chips. A related use was as a raw material feed by secondary lead smelters. When the debris is treated by the smelter, the lead is recovered and used as a raw material for processes such as battery manufacture. The identity of the lead is lost, and the waste is destroyed. Therefore, once the lead is recovered from the waste, liability under RCRA ends. Debris generated using expendable abrasives has been used as feedstock for portland cement manufacture, with the critical need being the aluminum, silicon, and iron content of the debris.

STABILIZATION METHODS

An understanding of stabilization techniques requires a basic understanding of the testing procedure. The Toxicity Characteristic Leaching Procedure (TCLP) is the test that determines whether or not a waste is hazardous. The test involves taking a small amount of waste 100 g (3.5 oz) and adding an amount of extraction fluid equivalent to 20 times the weight of the sample. This extraction fluid usually is a buffered acetic acid solution with a pH of 4.93 ± 0.05. (Orange juice is 3.8, typical cola is 2.5, vinegar is 3.1, and lemon juice is 2.5.) The mixture is tumbled for 18 h, filtered, and the filtrate—not the waste—is analyzed for lead content. It is only the soluble lead that matters in this test, not the total amount of lead in the waste.

As with all tests there are factors that affect the leachability of lead. Lead compounds are generally more soluble below a pH of 5 and above a pH of 11. If materials could be added to maintain the pH within this range, lead will not leach and the waste will not be hazardous. Lead is a metal. In the presence of some other metals, lead compounds will go through a process that changes the soluble ionic form of the metal to an insoluble metallic form. Various lead salts are so insoluble that even at a low or high pH, they are insoluble (stable). If the lead particles can be encapsulated to the point where water will not reach the lead in the 18 h of tumbling, the particles will also be stable. All of the stabilization technologies studied are based on these four mechanisms. The question, therefore, is not how to stabilize lead, but how stable is the treated debris.

A search of the literature and discussions with people in other industries uncovered some common methods for stabilizing lead-containing wastes. The U.S. EPA Handbook for Stabilization/ Solidification of Hazardous Wastes discusses stabilization/solidification processes based on mixing with portland cement, lime-fly ash, cement kiln dust, and lime kiln dust.(31) Stabilization of sledges from ferrous foundry melting furnace emission control devices have been reported to be rendered non-hazardous by mixing with iron.(32) Other research with foundry sands have indicated that treatment with lime or phosphates will also render the sand non-hazardous with regards to lead.(33) Another source of information on stabilization is the Code of Federal Regulations, which lists facilities that are allowed to treat specific types of wastes by specific processes. Some facilities are listed as being approved to treat wastes containing hazardous metals by treatment with lime.

A test program was performed with lead-containing blast debris to determine if common materials could be used to stabilize them. The materials chosen for testing were portland cement, lime, and iron. While State highway agencies are familiar with lime-fly ash mixtures and cement kiln dust, the variability of these materials was judged to be too great for inclusion in the test program. Samples of different types of abrasive blasting debris were obtained from lead-removal projects. They represented two types of abrasive-coal slag and mineral sand, and were used in the test program.

Portland Cement

Tables 17 and 18 present the results of the leachable lead content of unstabilized and stabilized wastes. The first sets of data in each table are for portland cement stabilized waste. The waste was mixed with the amount of portland cement presented in the table. Then water was added at a water-to-cement ratio of 0.5. At these low levels, a friable mass was obtained rather than blocks. The untreated coal-slag debris had a leachable lead level of 13.4 ppm. All portland cement additions between 10 and 25 percent by weight gave leachable lead levels below detectable limits. The portland cement was tested and also had a leachable lead level below detectable limits.

The untreated mineral sand debris had a leachable lead level of 54.6 ppm. Stabilization with portland cement using additions of 10 to 25 percent by weight resulted in leachable lead levels no greater than 0.5 ppm.

Table 17. Stabilization of coal debris.

Debris	Stabilizer	Level by Weight	Characteristic pH[1]	TCLP Solution[2]	Result (ppm)
Slag #1	PC/water	0%	3.4	1	13.4
	PC/water	10%	2.4	1	BDL[3]
	PC/water	15%	2.9	1	BDL[3]
	PC/water	20%	5.3	2	BDL[3]
	PC/water	25%	5.1	2	BDL[3]
	PC/water	100%	5.1	2	BDL[3]
Slag #2	lime	0%	3.4	1	27.5
	lime	5%	9.3	2	17.1
	lime	10%	11.1	2	0.26
	lime	15%	12.2	2	0.16
	lime	20%	10.9	2	14.9
	lime	30%	12.4	2	14.9
	lime	40%	12.6	2	13.5
	lime	50%	12.6	2	11.3
Slag #3	iron filings	0%	--	1	24.5
	iron filings	1%	--	1	0.13
	iron filings	2%	--	1	0.14
	iron filings	5%	--	1	0.10
	iron filings	10%	--	1	0.09
	G-40	0%	--	1	22.0
	G-40	2%	--	1	25.1
	G-40	4%	--	1	25.1
	G-40	6%	--	1	3.4
	G-40	8%	--	1	2.1
	G-40	10%	--	1	1.6

[1] Per EPA Method 1311.

[2] TCLP leaching solution 1 or 2, depending on characteristic pH.

[3] Below detectable limits (0.05 ppm).

Table 18. Stabilization of mineral sand debris.

Debris	Stabilizer	Level by Weight	Characteristic pH[1]	TCLP Solution[2]	Leachable Lead (ppm)
Sand #1	PC/water	0%	1.2	1	54.6
	PC/water	10%	2.3	1	BDL[1]
	PC/water	15%	3.1	1	0.3
	PC/water	20%	2.9	1	0.5
	PC/water	25%	4.1	1	0.5
	PC/water	100%	5.1	2	BDL[1]
Sand #2	G-80	0%	2.1	1	83.9
	G-80	1%	2.3	1	69.8
	G-80	2%	2.1	1	41.9
	G-80	3%	2.2	1	33.6
	G-80	4%	2.2	1	4.6
	G-80	5%	2.4	1	2.1
	G-80	6%	2.1	1	1.3
	G-80	7%	2.2	1	0.4
Sand #3	PM	0%	1.7	1	31.3
	PM	2%	1.7	1	19.4
	PM	4%	1.7	1	5.1
	PM	6%	1.6	1	1.3
	PM	8%	1.6	1	1.2
Sand #4	G-80-F	0%	2.3	1	67.7
	G-80-F	1%	2.3	1	56.7
	G-80-F	2%	2.4	1	12.8
	G-80-F	3%	2.3	1	1.4
	G-80-F	4%	2.8	1	0.7
	G-80-F	5%	2.8	1	0.5
	G-80-F	6%	2.5	1	0.4
	G-80-F	7%	2.4	1	0.4
	G-80-F	8%	2.6	1	0.3
	G-80-F	9%	2.3	1	0.4
	G-80-F	10%	2.4	1	0.3
	G-80-F	12%	2.4	1	0.3

[1] Per EPA Method 1311.

[2] TCLP leaching solution 1 or 2, depending on characteristic pH.

[3] Below detectable limits (0.05 ppm).

Lead is known to be a set retarder at low levels of addition, and to inhibit the set of portland cement at higher levels of addition at about 1 percent. All the formulations did harden. This would indicate that mixing the waste with portland cement was an encapsulation process rather than chemically tying up the lead in the hydration reactions. This hypothesis would appear to be realistic, considering that the lead pigments in the paint are surrounded by the paint binder. There is limited availability of the lead pigments. Other laboratories have stabilized lead-containing debris with portland cement with equal success.

Kansas DOT has developed a mix design of approximately 136.2 kg (300 lb) of waste, one sack of cement, and 28.4 l (7.5 gal) of water. After mixing in a portable mixer, the concrete is cast into blocks of approximately 0.9 m (3 ft) by 0.5 m (1.5 ft) by 0.3 m (1 ft) in size.

Another significant source of debris generated during abrasive blasting is the material captured in dust collectors. Stabilization of this debris with portland cement was examined, with the results presented in table 19. No significant change in leachable lead concentration was found when 10 percent by weight of portland cement was added to the debris without water. This differed from the blasting debris where a 10 percent dry addition of portland cement resulted in a significantly lower leachable lead concentration. When water was added to make a concrete, it was found that using a water/cement ratio less than 1:1 resulted in products that were still classified as a hazardous waste. At least a 2:1 water/cement ratio had to be used to achieve products with leachable lead concentrations significantly below 5 ppm.

Lime

A coal-slag debris was stabilized by mixing with hydrated lime. This debris had a leachable lead content of 27.5 ppm. Additions of lime varied from 5 to 50 percent by weight. The results showed that the 10- and 15-percent addition levels resulted in leachable lead content significantly below the action level of 5 ppm. However, higher levels of lime addition between 20 and 50 percent did not stabilize the waste to below 5 ppm leachable lead.

There appears to be no chemical reaction occurring between the lime and lead-containing waste, nor an encapsulation of the waste caused by solidification, as the mass did not solidify. Lead is known to be an amphoteric element, meaning that it has increased solubility in highly acidic and basic solutions, but limited solubility in neutral solutions. The characteristic pH's of the mixed wastes do show the lime additions to result in highly basic solutions (characteristic pH per EPA Method 1311 is measured after acid has been added). It may be that the lime controls the pH of the leaching solution used in the TCLP extraction procedure, and the lead is exposed to a neutral or basic extraction fluid rather than a slightly acidic one. The final pH's after extraction were not measured to prove this hypothesis. But the results did show that stabilizing lead-containing blasting debris with lime can be performed, but does require care. It was also concluded that long-term stability of the debris would be influenced by site-specific landfill conditions.

Table 19. Portland cement stabilization of dust collector fines.

% of Cement: Waste		Cement/Water Ratio	Leachable lead (ppm)
0	100	No Water	13.3
10	90	No Water	11.7
10	90	1 : 1	5.1
10	90	1 : 5	1.1
25	75	1 : 6*	8.9
25	75	1 : 1	3.6
25	75	1 : 2	0.7

*Kansas DOT Formula

Iron

Very fine iron filings were used to stabilize a coal-slag debris that had a leachable lead concentration of 24.5 ppm. A 1-percent addition of this finely ground iron to the debris resulted in a leachable lead concentration of 0.13 ppm. Further additions of finely ground iron up to 10 percent by weight resulted in the same or only slightly lower leachable lead compared to the 1-percent addition.

Abrasive Additives

The ability to treat a waste with finely ground iron particles led to further investigation of the use of iron as an abrasive additive. Adding the iron after the waste has been generated is treatment of a hazardous or potentially hazardous waste. While this can be performed, it does require the submittal of a waste analysis plan as previously described. The ability to use abrasive additives to generate a non-hazardous waste has considerable advantages. The non-hazardous waste can be subsequently transported and/or further stabilized without the need to use a licensed hazardous waste hauler, or submission and approval of a waste analysis plan for onsite treatment.

Finely ground iron particles would not be a good source of elemental iron to mix in with the abrasive, as obtaining a uniform mixture would be difficult. A better source would be steel grit or steel shot, which is of similar particle size to the abrasive. A series of experiments were performed using different sources and particle sizes of steel grit, including a G-40 a steel grit, a G-80 steel grit, a finer-than-normal G-80 steel grit (G-80-F), and a reprocessed grit that was a mixture of G-50, G-80, and G-120 steel grit (PM).

The results of these tests are reported in appendix A and are depicted graphically in figures 4 and 5. All the steel grits lowered the leachable lead concentration to below 5 ppm in the

4- to 6-percent addition level except for the G-40 shot. There was a rough correlation between particle size and efficacy, though other abrasive specific factors appear to be operating.

The explanation for the efficacy of iron in reducing leachable lead content appears to be an oxidation-reduction reaction similar to the electrochemical reaction that causes corrosion. Lead plates out on the iron surface from solution. The reaction is dependent upon surface area of the iron particles, hence, smaller particles are more effective as they contain a larger surface area on an equal weight basis. Similarly, steel shot, as round particles, have less surface area than an equivalent-sized particle with a rough surface.

Some States have already begun specifying the addition of 10-percent iron grit to slag or mineral sand abrasives. The choice of 10 percent by weight addition comes from the results presented above with a safety factor included. It should be noted that a proprietary blast abrasive additive is available that will generate a non-hazardous waste according to the data presented by the manufacturer.(34) The use of abrasive additives to slag or mineral sand abrasives does not solve the problem of minimizing the total amount of waste generated, which is a problem in some States where landfill space is limited. The use of blast additives is not without controversy about long-term stability of the debris.

Long-Term Stability

The addition of iron to the abrasive has been questioned based on the known chemistry of the stabilization. The plating reaction will only occur when the elemental iron and lead compounds are present together in solution. Therefore, a freshly generated waste placed in the TCLP leaching solution will have the constituents needed for the plating to occur. The question arises that if the material is placed in a landfill and the iron grit particles rust prior to the lead compounds being in intimate contact with the iron surface, the plating reaction will not occur. Therefore, the addition of iron may not be effective for long-term stability. This point is very important to State highway agencies, as they will be responsible for the waste *in memorium.*

The EPA has been questioned on this point and the EPA Characterization and Assessment Division of the Office of Solid Waste has issued a memorandum to all EPA Regional Offices stating that the hazardous waste regulations do not restrict the use of ingredients for the purpose of preventing waste from exhibiting a hazardous characteristic.(35) However, the generator should be aware that if adding iron to the abrasive only temporarily prevents lead from leaching from the waste, and the waste is disposed, the generator may be held liable under CERCLA for any environmental damages caused by the release of lead into the environment.

The long-term stability of non-hazardous, lead-containing wastes is a critical issue. Therefore tests were performed to determine the long-term stability of the waste. The first method examined was U.S. EPA Method 1320, Multiple Extraction Procedure (MEP). This test method was designed to simulate the leaching that a waste will undergo from repetitive precipitation of acid rain on an improperly designed sanitary landfill. This method consists of a TCLP extraction, followed by nine further extractions with a pH 3 solution that is a 60/40 mixture of sulfuric and nitric acid (a

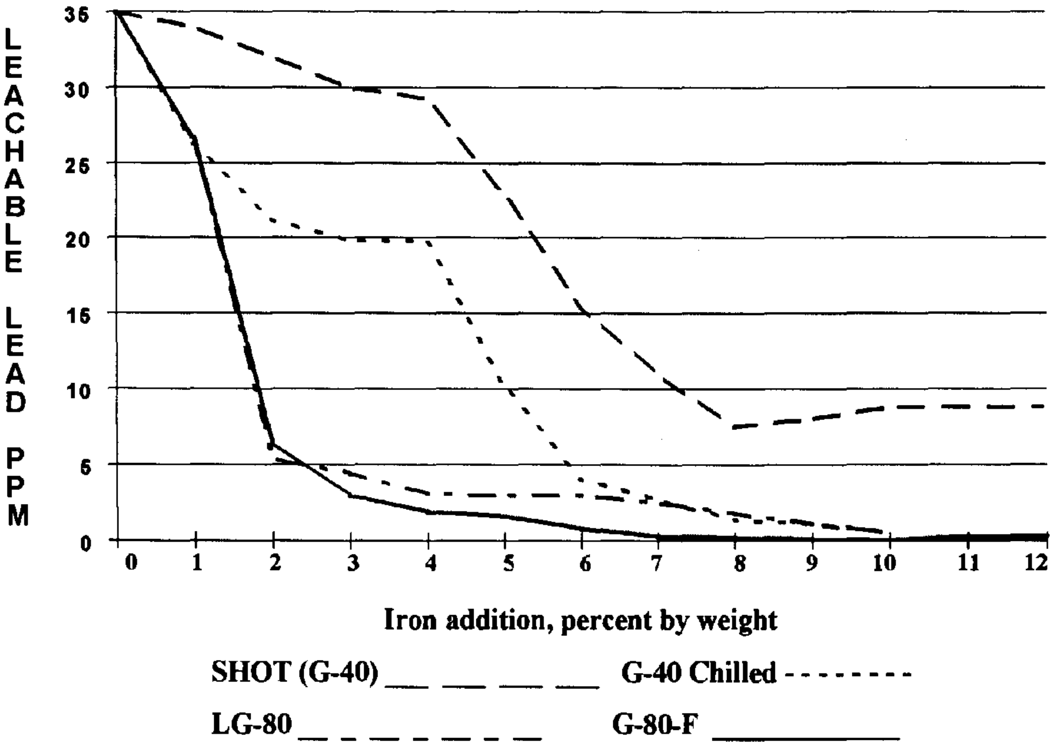

Figure 4. Leachable lead versus iron content for a laboratory debris sample.

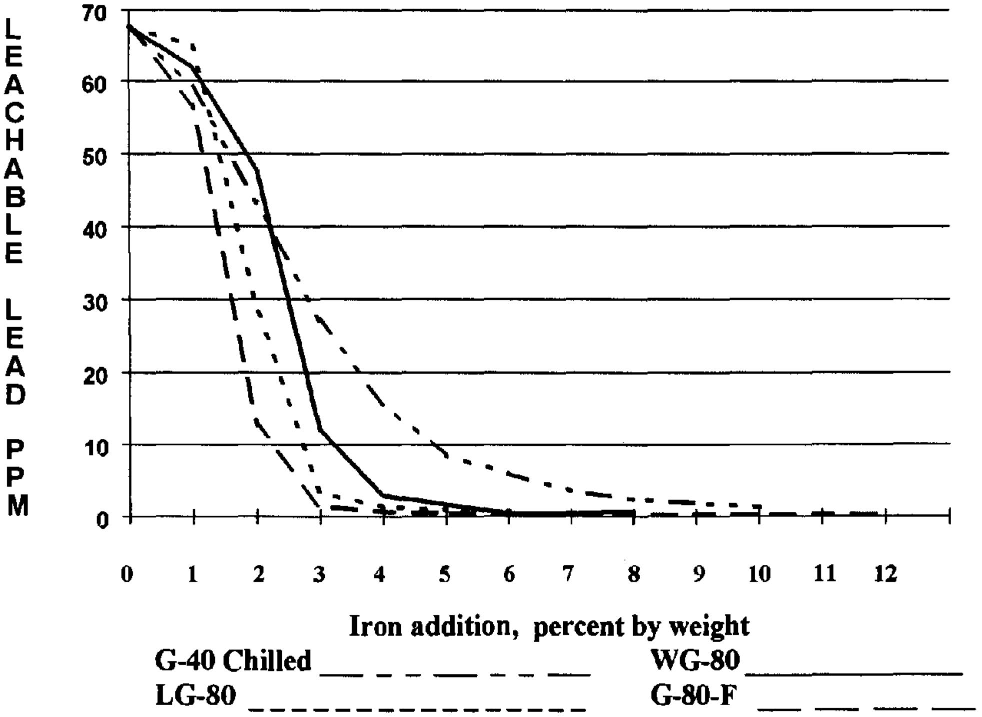

Figure 5. Leachable lead versus iron content for a field debris sample.

simulation of acid rain). Each cycle is supposed to represent 100 years in a landfill. Debris from removing lead-based paint with a mineral sand abrasive was tested by the MEP with the following stabilizing methods:

- Untreated waste.
- Waste with 6 percent G-50/80 steel grit.
- Waste with 10 percent G-50/80 steel grit.
- Waste with 15 percent proprietary additive.
- Waste with 22 percent portland cement and 11 percent water.
- Waste with 6 percent G-50/80 steel grit and post-stabilized with 22 percent portland cement and 11 percent water.

Appendix A reports the leachable lead concentration after each cycle for the samples that are presented in graphical form in figures 6 through 11. The untreated waste had a leachable lead concentration of 80 ppm. Further leaching cycles of the untreated waste had a much lower leachable lead concentration, but were still significantly above the 5-ppm regulatory limit (figure 6). Addition of 6 percent by weight of G-50/80 steel grit resulted in an initial leachable lead concentration of 1.3 ppm, which remained relatively constant through five multiple extractions. The leachable lead concentration began to increase on the sixth cycle, and exceeded the current regulatory limit on the ninth cycle (figure 7). Adding 10 percent by weight of the G-50/80 steel grit to the waste gave a similar response in leachable lead as a function of multiple extractions, with similar leachable lead concentrations through five cycles followed by increasing leachable lead through the next six cycles. The only difference was that the leachable lead had not reached 5 ppm by the 11th cycle (figure 7). A proprietary material was tested at the manufacturer's recommended addition level of 15 percent by weight addition. No change in leachable lead concentration was found for the 11 multiple extractions (figure 8).

The untreated waste and waste with 6 percent addition of G-50/80 steel grit were post-stabilized with portland cement. The wastes were mixed with 22-percent portland cement by weight, and water was added to give a 0.5 water/cement ratio. The concrete was allowed to cure, was crushed, and evaluated by the multiple-extraction procedure. The leachable lead concentrations were very low and consistent through the 11 cycles for the waste stabilized with portland cement (figure 9). For the waste treated with steel grit prior to portland cement stabilization, two anomalous results were obtained for the fourth and fifth cycle, with the other cycles all having very low leachable leads (figure 10). These two anomalous results were below the regulatory limit and may have resulted from laboratory error.

The results from these tests indicated that iron addition alone does not produce long-term stability of the waste. Further treatment is necessary. The results also showed that portland cement stabilization was very effective, as was the proprietary material.

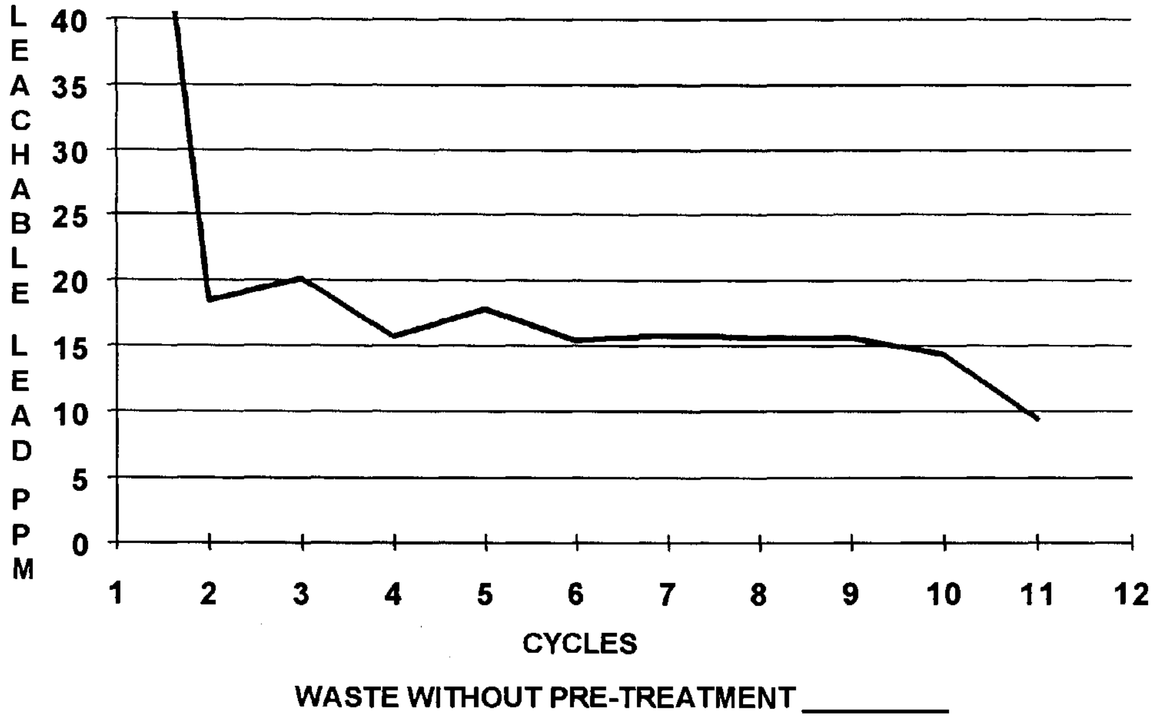

Figure 6. MEP results for untreated debris.

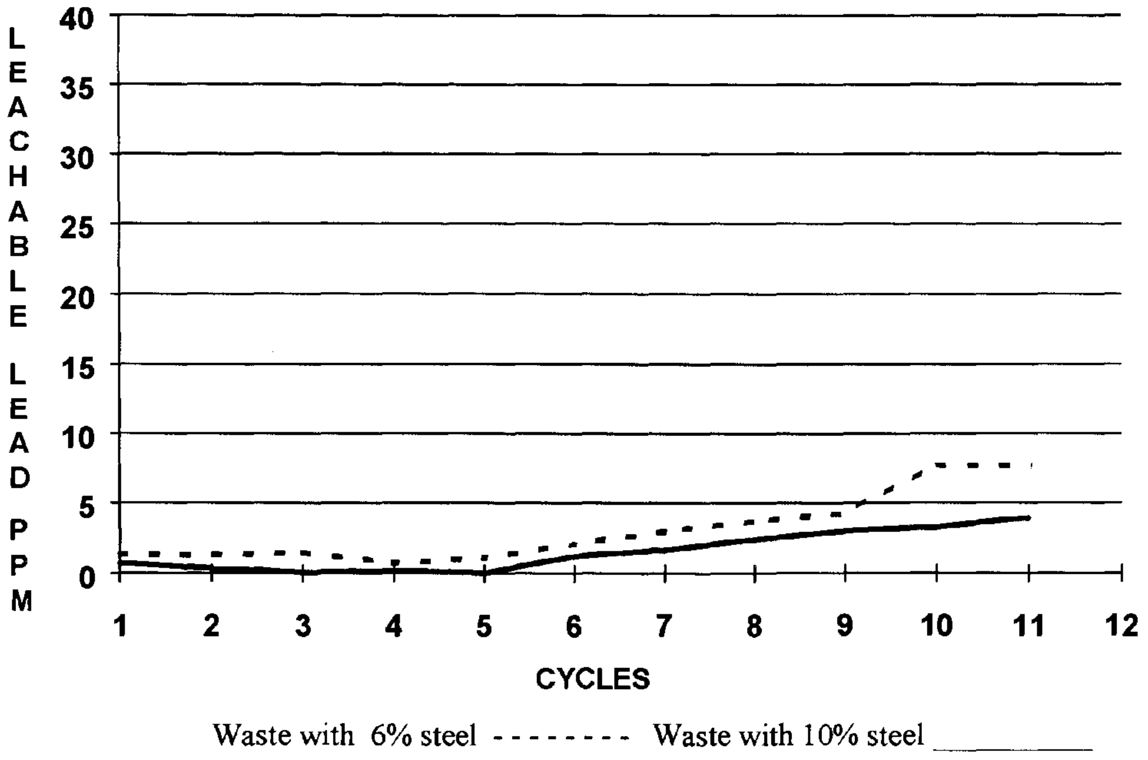

Figure 7. MEP results for debris incorporating steel grit .

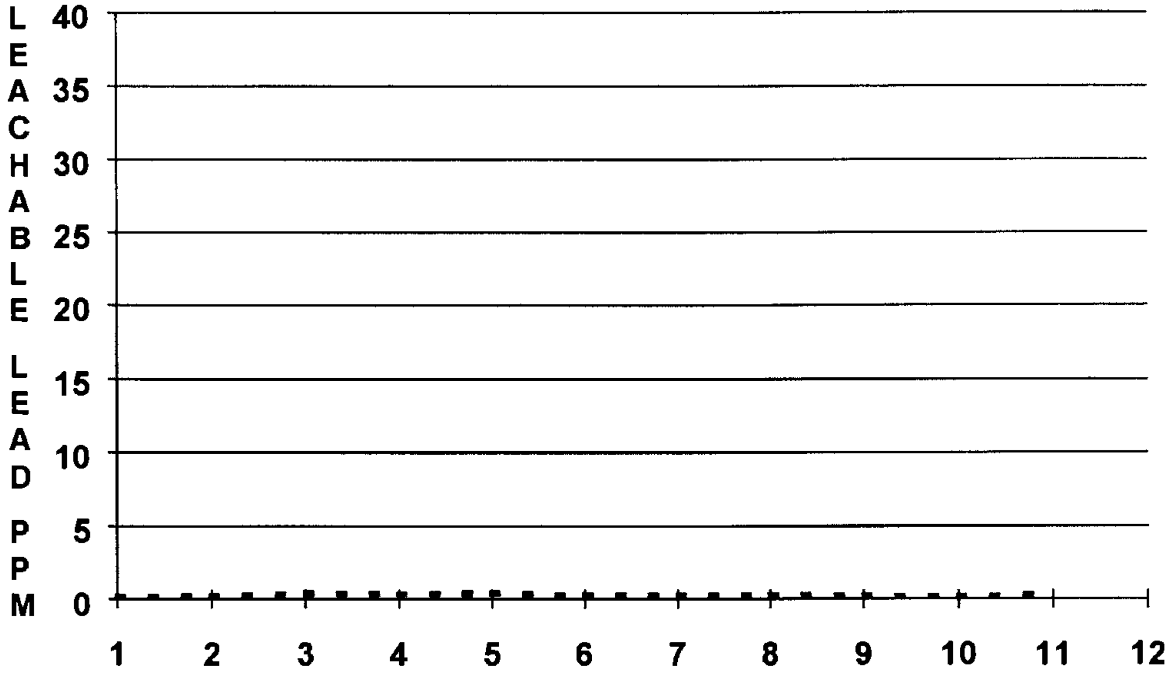

Figure 8. MEP results for debris with proprietary additive.

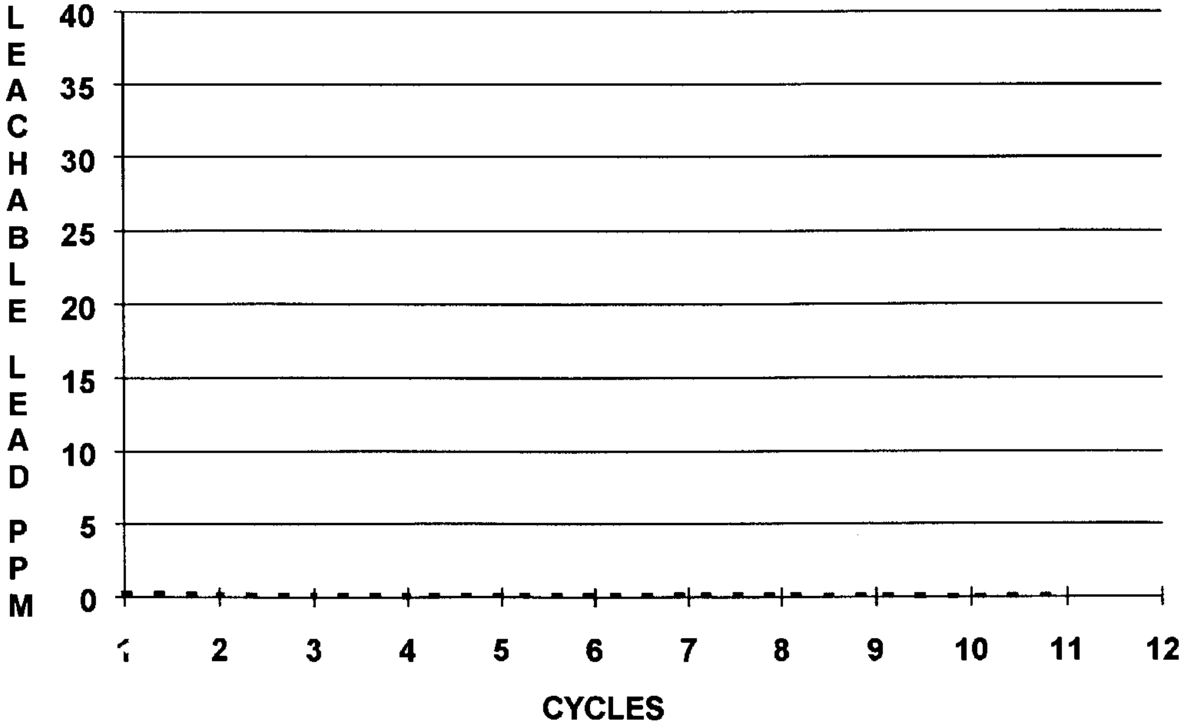

Figure 9. MEP results with Portland cement-stabilized debris.

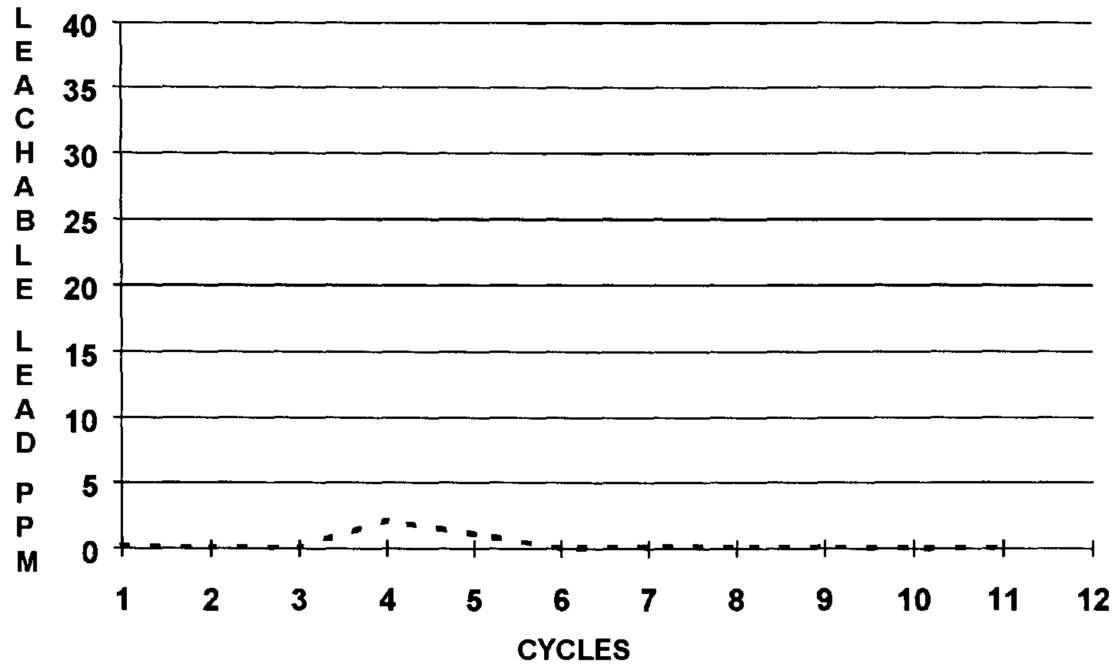

Figure 10. MEP results with pre-addition of 6-percent grit and post-addition of portland cement.

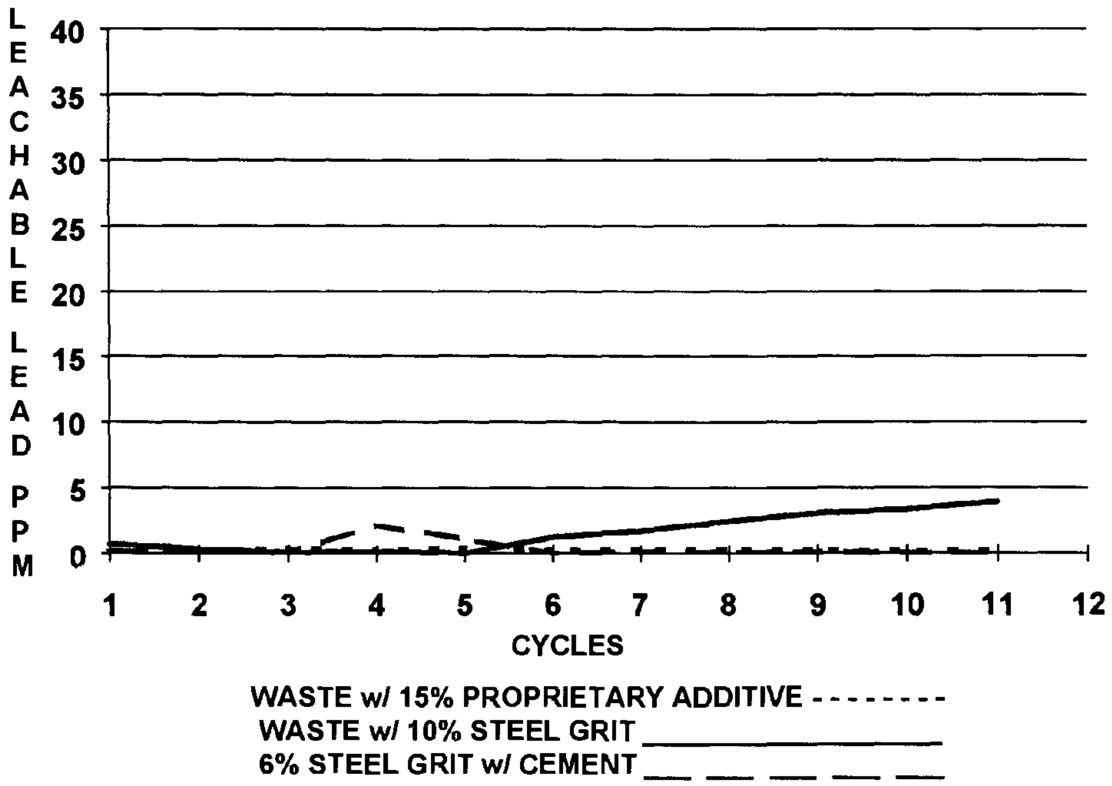

Figure 11. Comparison of MEP results.

During the time that the MEP tests were performed, an extra sample remained in a pan. The sample consisted of debris with added steel. The leachable lead concentration was <0.1 ppm. When the steel was removed with a magnet, the untreated debris had a leachable lead concentration of 70 ppm. TCLP extraction solution was poured in the pan, allowed to evaporate, and was replenished. This procedure was repeated for about 6 months. The waste was retested and found to have a leachable lead concentration of 70 ppm. The results of this crude test gave serious doubt as to the validity of the MEP procedure for predicting the longevity of the stability of lead-containing wastes.

Further experiments were performed to study long-term stability. These included a simulated landfill test and ASTM Method D 4874, Method for Leaching Solid Waste in a Column Apparatus. The simulated landfill tests were performed with three extraction fluids—TCLP solution, MEP acid solution, and distilled water. ASTM Method D 4874 was performed with TCLP solution. Results of these tests are reported in appendix A.

The results of the tests performed by ASTM Method D4874 were found to be inconclusive. The debris stabilized with portland cement leached between 6 and 7 ppm lead through the 7 days it was tested. Debris with 10 percent iron that was post-stabilized with portland cement leached between 3 and 5 ppm lead for 7 days, which subsequently dropped to below 2 ppm from day 12 to day 36. Debris that contained 10 percent iron with no further stabilization leached very little lead during 36 days of testing, being below detectable limits (<0.05 ppm) for the majority of analyses. These results were thought to be unusual based on the known chemistry of stabilization of lead by iron. The debris stabilized with the proprietary additive leached between 4 and 105 ppm lead for 35 days, including 28 ppm at day 1. These results were also thought to be unusual as leachable lead concentration of debris samples with the proprietary additive are rarely above 1.0 ppm when the debris is tested by the TCLP procedure (EPA Method 1311).

Three different leaching solutions were used for the simulated landfill test. Low or undetectable amounts of lead were found in the leachate for any of the stabilization methods when distilled water was used. Debris with 10 percent steel grit had measurable quantities of lead in the leachate with both TCLP and MEP solutions. A significant number of these measurements were above 5 ppm. Portland cement-stabilized debris or debris with 10 percent steel grit showed very low or undetectable amounts of lead in the leachate using MEP solution. Slightly higher amounts of leachable lead were found when TCLP solution was used, with all results except one being below 2.7 ppm lead. The debris with the proprietary additive had less than 1 ppm lead in the leachate when MEP solution was used, except for the last batch of solution where 11.1 ppm lead was found. When TCLP solution was used for leaching the debris with the proprietary additive, the lead in the leachate varied from 2.5 to 30 ppm. Note that the proprietary additive was added to the debris in its original form for the laboratory tests. Had the material been pulverized as normally occurs when blasting, the results may have been different.

The results indicated that portland cement stabilization of debris, even if the debris was generated by adding steel to the abrasive, provided the most consistent results for the solutions tested. The tests also confirmed the lack of long-term stability of debris where a source of iron is incorporated as a blast-abrasive additive. The results with the proprietary additive showed high leachable lead concentrations using TCLP solution, and low leachable lead concentrations with the other two solutions.

The data also indicated that TCLP solution was more aggressive than MEP solution or distilled water. TCLP solution is an acetic acid buffer, which supposedly simulates the environment in a sanitary landfill. The MEP solution simulates acid rain. The results of the tests on long term stability appear to indicate that less risk is associated with disposal of debris in a non-sanitary landfill or landfill cell. This assumes that the MEP solution sufficiently characterizes the chemistry of a non-sanitary landfill. Further research is needed.

RECLAMATION

Part of the research included a search for methods of reuse or reclamation of lead paint-containing debris. No significant use for abrasive-blasting debris could be found.

Discussions with a secondary smelter indicated that they do use lead-containing wastes in their smelter to recover the lead. Decisions on sources are made on a case-by-case basis. They have smelted paint chips and have even accepted lead paint-coated structural steel (cut into small pieces), but they do not accept gross debris from expendable abrasives. The amount they charge for taking the waste is dependent upon an assay of the waste. If the assay shows aluminum, magnesium, or high levels of fluoride, sulfide, or chloride, they cannot use the material. Iron is used as a flux in the furnace and would be acceptable. It would appear, therefore, that debris from the use of recycled steel abrasive with its high iron and lead content would be a desirable source for the smelter. Potential liability for the State highway agency would also be small. Even in the worst-case scenario where a site cleanup would be required, there would be many identifiable suppliers of lead.

Recently, the supplier of a proprietary blast additive announced that they will be purchasing non-hazardous, surface preparation debris for use as feedstock for cement kilns. This will only apply to certain abrasives, as the material being reclaimed is the iron, aluminum, and silicone content in the abrasive. Once the debris has been used to manufacture cement, the waste will be unidentifiable. Cement kilns have their own waste streams, and liability to the State highway agency for lead in the kiln's waste would have to be investigated.

V. MAINTENANCE-PAINTING STRATEGIES

Compliance with the regulations has had a significant impact on the cost of painting projects. This has generated increased interest in alternate coatings management strategies. The options include:

- Total Coating Removal and Replacement.
- Zone Painting.
- Spot Cleaning and Painting.

Each option has its advantages and disadvantages.

TOTAL COATING REMOVAL

Total coating removal and replacement is the most costly alternative. It will generate the greatest amount of waste and high lead exposure to workers, and will require extensive protection of the environment. Substantial containment structures will be required, depending on surface preparation method. However, it does eliminate the lead from the structure, which will not influence future coatings maintenance. This option may be the only alternative due to the extent of coating deterioration.

ZONE PAINTING

Zone painting is a strategy to consider when there are definable areas on the structure where coating degradation is more excessive than other areas, i.e., expansion joint areas. The coating systems would be completely removed and replaced on the badly degraded area, and spot maintenance would be performed on the rest of the structure. Zone painting would also consider upgrading the coating system for the area where coating degradation is occurring the fastest, to even out the failure rate to be consistent with other parts of the structure. States that use this option totally remove the coating anywhere from 1 m (3 ft) to 2 m (6 ft) from both sides of the joint.

Zone painting can be performed by itself, or in conjunction with spot touch-up on the remainder of the structure. Surface preparation on the remainder of the structure usually consists of hand- or power-tool cleaning, which generates significantly less waste and dust than abrasive blasting, thus requiring lower levels of containment for those portions of the bridge. One potential disadvantage of zone painting is the condition of the existing coating and the compatibility of the new coating with the existing coating. The new coating must be compatible with the existing coating so lifting does not occur at the overlap. The existing coating must have adequate integrity to withstand potential lifting or disbondment if spot repairs and application of a new top coat are performed on the remainder of the structure.

The advantage of zone painting is that the total coating system is not arbitrarily removed because of severe coating failure and/or corrosion in limited areas. If the coating system is upgraded in the zone area, then the coating materials are not indiscriminately applied to the whole structure. Tight containment is only needed in the zone areas. The cost of zone painting will be less than total repainting.

Spot Cleaning and Painting

Spot cleaning and painting includes surface preparation of rusted and failed areas only, followed by spot priming and spot top coating. Mild surface preparation methods will be used, which will minimize containment requirements and minimize the amount of debris generated. This is the least costly strategy, but results in a coating that is aesthetically unpleasing.

Spot cleaning, spot priming, and application of a new top coat to the entire structure is similar to spot cleaning and painting. The difference is the application of a new top coat to the entire surface, which will extend the life of the entire coating system and be more aesthetically pleasing than just spot painting.

Assessing Coating Condition

Spot cleaning options can only be performed if the existing coating is amenable to repair. The existing coating must be adequately bonded and have sufficient, internal integrity to accept a new top coat. The extent of corrosion is also an important factor. If it is too extensive, the number of fractured edges resulting from the surface preparation may not be conducive to long-term performance of the repaired system. General guidelines presented in the SSPC Industrial Lead Paint Removal and Abatement Tutorial to determine if the coating system is a candidate for repair are presented in table 20.

The substrate condition, i.e., previously blast cleaned or still containing mill scale, is used to supplement the action dictated by the tests above. Results from the tests indicate the coating system is rated as a possible candidate if the substrate had been previously blast cleaned, and total removal would be indicated if the substrate had not been previously blast cleaned.

Table 20. Coating repair candidates.[1]

Coating Attribute	Likely	Possible Candidate	Unlikely Candidate
Corrosion[2]	<10%	10-17%	>17%
Knife Adhesion[3]	>2A or 2B	1A or 1B	0A or 0B
Thickness[4]	<500 μm (20 mils)	500 - 760 μm (20-30 mils)	>760 μm (30 mils)
Substrate[5]			

[1] Table for general guidance only. Other variables enter into decision process.
[2] SSPC-Vis 2.
[3] ASTM D3359.
[4] SSPC-PA 2.
[5] Use the presence of rust or mill scale to sway borderline decisions based on the above data.

It is good practice to conduct a patch test to assess coating compatibility, especially when using a paint that has not been used before or has been reformulated to meet volatile organic compound (VOC) content.(25) This encompasses cleaning test areas of at least 0.1 m^2 (1 ft^2) by a method similar to that which will be used when the bridge is painted and applying the test coating. After curing, the test patch is examined for wrinkling, blistering, mudcracking, checking, cracking, peeling, lifting, and disbindment. Adhesion is measured per ASTM D3359 and the results are assessed in comparison to the initial adhesion.(26) The preferred method is to use long-term curing, with a minimum of 6 months preferred encompassing the most severe seasonal weathering changes. Short-term curing of 14 days at 10 °C (50 °F) to 7 days at 32 °C (90 °F) provides more rapid (though less predictive) evaluation of results.

SHOP BLASTING

There have been very few (if any) projects performed where lead has been removed in the shop since the OSHA lead requirements have been issued. It is believed that when all the ramifications of the new law concerning employees are understood and enforced, it will not be practical to perform lead removal in a shop unless the shop has been specifically designed for that purpose. Due to lack of demand and high transportation costs, this seems unlikely.

STEEL REPLACEMENT

Steel replacement or replacement with pre-stressed concrete beams should be considered if the deck has to be removed. When replacing decks, it can be easy to replace beams, and according to some, not any more expensive, especially in environmentally sensitive areas.(67) The important factor is that deck removal or repair to existing structural steel was necessary for reasons other than painting. If decks are scheduled to be removed in 10 to 15 years, spot painting would be a good choice for consideration.

VI. SURFACE PREPARATION WITH ABRASIVES

Dry abrasive blasting is one of the most efficient methods of surface preparation for total coating removal. It is capable of removing all contaminants from the surface, including paint, rust, and mill scale. Abrasive blasting is effective on almost any configuration of steel, including corners, angles, nuts, bolts, rivets, and almost complex shapes. The main areas where abrasive blasting has limited effectiveness is tight spaces, such as between back-to-back angles (where no technique is fully effective). Abrasive blasting also imparts a surface profile (roughness) into the substrate to promote coating adhesion. It is one of the most productive methods of surface preparation. There are four industry grades of abrasive blasting: Brush-Off (SSPC-SP7), Commercial (SSPC-SP6), Near-White Metal (SSPC-SP10), and White Metal (SSPC-SP5). Depending upon the initial condition of the steel and final cleanliness grade specified, productivity ranges from about 4.6 to 46.5 m^2/h (50 to 500 ft^2/h). For the purposes of this report, a production rate of 9.3 m^2/h (100 ft^2/h) will be considered to be a realistic cleaning rate for achieving a Near-White (SSPC-SP10) level of cleanliness on girder bridges.

EXPENDABLE ABRASIVES

A number of different abrasives are used for abrasive blasting. The most typical are expendable abrasives, i.e., mineral sands and slags. Cleaning to SSPC-SP10 requires 9.8 to 49 kg/m^2 (2 to 10 lb/ft^2) of abrasive, depending on the initial condition of the substrate and desired cleaning level. Medford reported recovery efficiencies of 90.5 and 96.4 percent for two bridge painting projects performed in 1991.(38) The calculations of recovery efficiency included an estimate for the weight of paint and mill scale on the structure. Therefore, the amount of debris generated from dry abrasive blasting is about equal to the weight of abrasive used.

Expandable abrasives produce a large amount of dust. Slags and sands are friable. About 35 to 95 percent of the abrasive disintegrates upon impact with the surface, depending upon type and quality of the abrasive supply. Reclaiming the useable fraction is not cost-effective, hence the term "expendable abrasive." Breakdown of the abrasive makes a significant contribution to the amount of dust. This added dust from breakdown of the abrasive contributes to the particulates that can potentially be emitted from the project, resulting in possible exceedance of the CAA restriction on particulates. While the particulates would not be related to the amount of lead being discharged, dust clouds certainly bring more attention to the project.

The debris generated from removal of lead-based coatings with expendable abrasives has a very high probability of being classified as a hazardous waste. One method of lowering the probability is to use more abrasive than required by good blasting practices. This actually is dilution, a technique which is frowned upon by the regulatory agencies. It is also possible to specify a higher level of cleanliness, i.e., SSPC-SP5, White Metal, which requires more abrasive per square foot, hence lower leachable lead concentration of the waste due to the added abrasive. This method would not ensure that the waste generated would be non-hazardous, as there are a number of factors that determine the leachable lead concentration in a waste that cannot be controlled.

RECYCLABLE ABRASIVES

It is also possible to use recyclable abrasives such as steel, aluminum oxide, and garnet. Recyclable abrasives minimize the amount of waste generated as the useable abrasive is reclaimed for reuse. Recyclable abrasives do not pulverize as much as expendable abrasives. Less dust is generated as the contribution to the dust from the breakdown of the abrasive particles is less than expendable abrasives. The recyclable abrasive most commonly used in the open abrasive blasting mode is steel grit. Contractors who have used this equipment report a 10 to 20 percent increase in productivity when using steel as compared to sands or slags. It is not known if this is inherent in the process or results from improved worker visibility due to less dust.

One advantage of metallic abrasives is that they allow blasting to be performed at higher pressures. The normally desired blast pressures for expendable abrasives is 621 to 698 kPa (90 to 100 lbf /in^2) at the nozzle. Compressors are currently available that allow maintenance of 862 to 965 kPa (125 to 140 lbf /in^2) at the nozzle. A general rule of thumb is that each 70 kPa (10 lbf/in^2) increase in pressure results in a 15 percent increase in productivity. However, most slag abrasives break down above 698 kPa (100 lbf /in^2) and increased productivity is not achieved from higher pressures. Increasing productivity by 30 to 50 percent by high-pressure blasting with steel abrasive is a seldom recognized advantage.

Technically, steel can be recycled over 200 times. Practically, there are losses of abrasive due to incomplete recovery from containment or loss of good abrasive in the recycling step. Information on how much abrasive is used per unit is scarce, as the equipment is not emptied when the project is completed. More data exist on the amount of waste generated. Olson and Burbank reported disposing of 80 barrels of debris from cleaning 49 400 m^2 (532,000 ft^2) of steel from the Chesapeake Bay Bridge Tunnel Project, with a steel grit recovery rate of 92 to 96 percent.(41) Using a weight per barrel of debris of 454 kg (1,000 lb), this translates to 0.7 kg/m^2 (0.15 lb/ft^2). They estimated the amount of debris that would be generated from this project at 3 x 10^6 kg (3,310 tons), or 60.5 kg/m^2 (12.4 lb/ft^2). Lyras reports data for waste generation based on actual projects as 43 drums of waste from a 14 000-m^2 (150,000-ft^2) structure, or 1.42 kg/m^2 (0.29 lb/ft^2) for steel abrasive.(42) The same size structure blast cleaned with boiler slag would generate 938 drums of waste, or 30.5 kg/m^2 (6.25 lb/ft^2). This is a 95 percent reduction in the amount of waste generated by using recyclable steel abrasive. Crowns reported generating 907 kg (2,000 lb) of debris per day when using steel abrasive, and 13.6 x 10^3 kg (30,000 lb) per day with the same crew size when using sand abrasive, or a reduction of 93 percent in the waste generated.(43) The data indicate that use of recyclable steel abrasive will generate less than 10 percent waste compared to use of expendable abrasives.

A major concern with use of recyclable abrasives has been the efficiency of the recycling units. Steel recycling units were originally developed mainly for use in shipyards for cleaning the insides of tanks and bilges on ships, which generally were not coated with lead-based paints. Recovering the useable abrasive from the debris consisted of screening off the oversized particles, followed by removing the fine particles with a cyclone separator. These units were about 70 percent efficient at removing the unwanted materials.(42) It was found that these or similar units were not effective at cleaning the debris when adapted to use on lead-paint-removal projects. The abrasive would become dustier with each recycling, introducing a fine, lead-containing dust into containment through the blast nozzles. Visibility would deteriorate and worker exposure levels to lead would increase with each recycling of the abrasive.

Equipment manufacturers and contractors responded to the problem by modifying the recycling unit. Advances in abrasive recycling equipment have included such steps as: metering the debris into the unit, modifications to and better control of the air-wash system, incorporating magnetic separation, and adding impinger plates to dislodge lead-containing particles. Significant advances in abrasive recycling have been made in the last 4 or 5 years.

The probiems with recycling units led to the desire and need to quantify their efficiency. In 1991, Hitzrot suggested quantifying efficiency based on the amount of fine particles in the recycled mix.(43) He proposed that no more than 1 percent by weight of fines be present as determined by the amount of material passing through a #70 sieve. The SSPC Abrasives Committee has begun development of a standard for recycled metal abrasives. The June 23, 1993 draft of this standard proposes no more than 1 percent by weight passing through a #100 sieve. As the amount of lead in the recycled abrasive is also important, it appears that the SSPC standard will also address this issue. Current indications are that a limit of 1,000 ppm lead in the recycled abrasive will be the upper limit. Recently, Connecticut DOT has added a requirement for no more than 50 ppm lead by weight in recycled steel abrasives.

Factors that affect the amount of lead measured in recycled steel abrasive include the amount of lead in the virgin abrasive, the efficiency of the recycling unit, and the variability between samples. Sampling variability alone indicates that the lowest level of lead in recyclable abrasive that can be measured is approximately 200 ppm, and indications of current recycling technology indicate that about 1,000 ppm total lead is the lowest level that can be achieved (see appendix A). Data do not exist at present to indicate if 1,000 ppm is realistic. This amount may even be too stringent.

The use of recyclable abrasives compared to expendable abrasives has other strengths and weaknesses. Steel abrasives do rust in the presence of moisture and require dehumidified air. The steel can even rust when stored overnight in a blast pot if knowledge of temperature, humidity, and dew point is not followed. There is a risk to the contractor of loosing a significant amount of expensive abrasive, and time to dismantle and clean out a clogged blast pot. State highway agencies may look upon this as a positive attribute, as it indicates a certain level of competence. A contractor who owns and is capable of blasting with steel requires a certain knowledge, which also should include how to blast productively and quality surface preparation.

Steel-recycling equipment is expensive. A recycling unit and ancillary equipment costs between $250,000 and $500,000. The cost of abrasive blasting is determined, in part, by the amortized cost of purchase and maintenance of the equipment. Determining the amortized cost is dependent upon the useful life of the equipment. These units have not been in existence for a long enough period of time to determine this life. The charges associated with use of the equipment will depend upon how many hours per year it is used. Requiring the use of abrasive recycling will maximize use of the equipment. Cost is discussed more fully later in this report.

Abrasive-recycling equipment can be divided into two categories: self-contained units and central recycling facilities. Self-contained units have the recycling equipment and blast pot(s) all mounted as a unit. Central recycling facilities are portable, but only contain the equipment needed to recycle the abrasive. Central recycling units are more appropriate for large bridges where surface preparation is being performed at multiple locations, bridges with limited access for equipment, or contracts requiring painting of multiple bridges where work can be performed concurrently. While there may be a cost advantage to the contractor for buying a central recycling facility as they already own blast pots, there would be no difference to the State highway agency as they would be charged for all the equipment.

A unique problem associated with the use of steel abrasive is site contamination. If spills of debris or recycled abrasive are not picked up, the steel will rust. It is difficult to distinguish rusted steel from lead-paint dust. This has resulted in situations where deposits on the ground have raised concern about spills of lead-containing debris, which was actually non-hazardous steel. Another site contamination problem has been deposits of a fine, red dust on the blast-cleaned surface. This dust adheres tenaciously and cannot be removed by normal cleaning techniques as blowing down or vacuuming. It appears that this lead-containing dust has electrostatic properties that cause it to stick to the surface. This can possibly result from the use of dehumidified air required to keep the steel dry. Another common occurrence has been dust adhering to the surface on adjacent coated steel where there may have been a leak in containment. This can easily be removed by washing, but does require extra work, including access.

All methods have advantages and disadvantages. The purpose of this section is to list these disadvantages and offer workable solutions if possible. Recyclable abrasives are generally steel grit. Disposable abrasives could be any of a wide variety of abrasives typical of the highway market.

STEEL GRITS

Steel grits have some very powerful advantages. If the goal is to reduce the volume of waste, then steel grit is the obvious choice. Note that though the volume of waste is reduced, the volume of lead-containing material is not reduced, just concentrated. If the goal is to reduce the volume of *hazardous* waste, then the issue is more complex. Steel grits also allow very good visibility in containment. Grit blasting requires the use of typical blasting equipment that has been modified to make absolutely sure there is no moisture in the air system. Vacuum air, or gravity, or a combination of these is used to collect abrasive and transfer it to the recycling equipment. The recycling equipment removes the paint chips and transfers the cleaned abrasive back to the blasting pots.

The fact is that until there are enforceable guidelines on how clean the abrasive must be in order to be considered suitable for reuse, there is not a good method of comparison. The biggest threat to steel grit blast cleaning is overspecification of the cleanliness of recycled abrasive. Values as low as 50 ppm have been specified. On a production basis, this value is unachievable. In fact, many steel abrasives contain this amount of lead prior to being used. If values in this range are specified, the use of steel recycling techniques will cease to be a viable alternative. This would be a major mistake. Therefore, considerable effort was spent attempting to determine an achievable level of cleanliness.

All the data for this determination are contained in appendix A. It is apparent that there are problems in measuring lead in an iron matrix and that laboratories must be very careful in the analysis. In addition, sampling variability is quite high. Given these two complications, it is believed that 1000 ppm is the best level that currently should be specified. It may be possible to reduce the level as more data become available. Based on work performed for other projects, it is apparent that levels currently in the range of 600 to 800 mg/kg are typical of properly designed and operating equipment. Poorly designed and/or poorly operating equipment typically display lead values greater than 1500 ppm for recycled abrasive. Thus, a level of 1000 ppm seems to separate the good from the bad.

The following are problems that have been identified on steel grit projects and possible solutions.

Smut

Even after many years of exposure, some alkyd paints are sticky or greasy when removed in very small particles. This dust sticks to everything, especially previously blasted or primed surfaces, and can be very difficult to remove. There may also be a contribution to this problem from static electricity. The incorporation of small amounts of disposable abrasives into the steel grit solves the problem. With the addition of disposable abrasive, the dust does not adhere to previously blasted or primed surfaces.

Steel Grit on Painted Surfaces

This problem occurs due to small amounts of abrasive that escape containment and collect on the top of the bottom flange outside of containment. This steel grit is easily removed prior to its getting wet by merely blowing down the surface. If the steel grit gets wet, it usually requires scraping to remove it and leaves unsightly rust stains on the freshly painted surfaces. These rust stains are often confused with a paint failure.

Water

Water can cause a great many problems with steel grits. On structures with poor concrete decks, even small showers can leak through the decks and corrode the abrasive. Deck drains should always be covered. (On one monitored project, a street-cleaning operation destroyed a large amount of abrasive because street drains were not plugged.) On-ground collection systems must take into account drainage or runoff patterns from the surrounding area.

Wastes

Wastes from steel abrasive blasting can be recycled. Due to its usually high lead content, this is the method of choice. If waste stabilization with cement is chosen, extreme care must be taken with the concrete mix design. The dust from the reclaimer and dust collectors is highly absorbent of moisture and much more water (double or triple) must be added to result in a stable mixture.

Weight of Abrasive

Steel abrasives are very heavy per unit volume. What may appear as a typical amount collecting on support platforms may be typical in volume for such abrasives as coal slags, but not typical in weight. Steel abrasives must be removed from support structures often.

VII. OTHER SURFACE PREPARATION METHODS

The concern over lead has resulted in an increased awareness of other surface preparation methods. This includes both commercially available surface preparation methods and development of new technology. There are various classifications of surface preparation methods. The two most common classifications are cleaning (paint removal) versus surface preparation, and high-dusting methods versus low-dusting methods. Cleaning methods are those that only remove the paint. The options are then to prepare the surface to a higher level of cleanliness, or to coat the surface with a compatible coating system. Surface preparation methods are those that remove the lead-containing paint, rust, and mill scale, and impart a surface profile in one step. Current technology dictates a cleaned, roughened surface for maximum coating life.

Classification by high- versus low-dusting methods is more appropriate for indicating containment needs and worker exposure. High-dusting methods require more complex containment to protect the environment, and result in higher exposure to workers. Low-dusting methods require less containment and lower exposure to workers.

Commercially available surface preparation and cleaning methods include:

- Hand- and power-tool cleaning.
- Chemical stripping.
- Wet abrasive blasting.
- Vacuum blasting.
- Water blasting.
- Water blasting with abrasive injection.
- Power-tool cleaning to bare metal.
- Other cleaning methods.

The following is a discussion of surface preparation methods with regard to various factors related to performing the work desired and environmental issues.

HAND- AND POWER-TOOL CLEANING

Hand- and power-tool cleaning are recognized methods of surface preparation described in SSPC-SP2 and SSPC-SP3, respectively. Vacuum-shrouded power tools are available, and in some instances, contractors have made vacuum-shrouded hand tools. The intent of both hand- and power-tool cleaning is to remove loose coating, loose rust, loose mill scale, and other loose contaminants. Intact materials remain on the surface. These cleaning methods are most appropriate when the intact coating is in relatively good condition and the existing coating can be maintained. Cleaning rates on the order of 23 to 37 m^2/h (250 to 400 ft^2/h) are reasonable rates, depending on the condition of the coating. These rates should not be compared to other surface-preparation methods where total coating removal is performed.

Containment requirements for hand- and power-tool cleaning depends upon the method used, and whether or not the tools are shrouded. Major requirements for containment are to minimize the loss of the paint chips generated and to keep the ground from being contaminated. Hand-tool cleaning does not produce a significant amount of dust and the probability of exceeding Clean Air Act (CAA) limits is extremely low. Though unshrouded power tools will generate significantly more dust than hand tools, the probability of exceeding CAA limits is still low. Measurements made on one project where five workers were simultaneously using unshrouded power tools with hanging drapes as the containment found no CAA violations, though measurable increases in lead and particulates in the air in the vicinity of the bridge were measured.(44) In most cases, containment will not require a ventilation system, though it may be necessary when unshrouded power tools are used, depending on worker exposure levels and sensitivity of the work area.

Exposure levels to workers can be above the PEL, depending on the amount of lead in the paint and the tools being used. The U.S. Navy reported that workers were exposed to levels of lead above the PEL when sanding paint containing as little as 0.2 percent lead, but below the PEL for workers using chipping hammers on coating containing up to 6.0 percent lead.(26) OSHA reported lead exposures between 6 and 167 $\mu g/m^3$ with an average of 45 $\mu g/m^3$ for 6 observations for hand scraping, and between 1 and 20 600 $\mu g/m^3$ with an average of 735 $\mu g/m^3$ for 65 observations of power-tool use on steel structures.(25) The OSHA Construction Industry Lead Standard requires protecting workers to a presumed exposure of 500 $\mu g/m^3$ for hand- and vacuum-shrouded power tool cleaning, and 2500 $\mu g/m^3$ for unshrouded power-tool cleaning, during initial exposure assessment.

The amount of waste generated from hand- and power-tool cleaning is relatively small. There are approximately 310 to 920 gm/m^2 (1 to 3 oz/ft^2) of coating on the surface, depending on the thickness of the coating. As hand- and power-tool cleaning removes only loose material, the coating will be removed from no more than about 10 to 15 percent of the surface (if more coating is removed, the structure was not a candidate for maintenance painting). Therefore, only a few tenths of an ounce of waste per square foot of the entire structure will be generated. The waste generated from removing lead-based paints has a high probability of being classified as a hazardous waste, and should be handled accordingly.

CHEMICAL STRIPPING

Chemical stripping is a method of removing paint using chemical agents.(47,48) The stripper is applied to the surface, left in place for an allotted time, and then removed by scraping or with pressurized water. Chemical strippers remove only the paint. The process will not remove rust or mill scale, nor impart a surface profile. If a clean, roughened surface is desired, further preparation of the surface must be performed. This is usually accomplished with abrasive blasting.

Chemical strippers come in two basic categories, alkaline strippers and solvent-based strippers. Alkaline strippers are used mainly on oil-based paints, though they generally do not work on coatings that contain aluminum flake pigments. Solvent-based strippers are used on other coating types, such as epoxies. No matter which type of stripper is used, test patches must be placed to determine the amount of time it takes for the stripper to remove the coating. The amount of time is dependent on the existing coating and temperature. It can range from 1 to 12 h. Application rates are usually in the range of 0.25 to 1.23 m^2/L (10 to 50 ft^2/gal). It may be necessary to apply a thin "tack coat" prior to application of the full thickness. Most strippers can be applied by airless spray, as well as brushing or troweling. Hand application can be performed at a rate of approximately 9.3 m^2/man-h (100 ft^2/man-h). Spray application can be performed at about 190 to 370 m^2/day (2,000 to 4,000 ft^2/day). During the time the stripper is on the surface, it must be protected from rain and vibration. It also should not be allowed to dry out. Multiple applications may be necessary depending on the number and types of coating on the structure. The stripper is removed after the determined amount of time by scraping, washing, or scrubbing. The surface may need to be neutralized after the stripper and paint is removed, especially for alkaline strippers. It most definitely will require final washing with clean water, no matter what type of stripper is used. Chemical strippers can be applied to almost all shapes and configurations found on bridges, though recovery of the sludge after removal may require some thought on some configurations. Based on testing using a common chemical stripper, it is apparent that some strippers will have difficulty obtaining the required thickness in one application. In addition, due to traffic vibrations in many highway bridges (the bridge usually remains open to traffic during paint removal), some chemical strippers when applied at required thicknesses in one application simply vibrate from the surface. Multiple passes with significant (½ to 1 h or more) flash times may be required.

Containment during application and removal of the stripper is mainly for collection of the debris. This usually consists of chemically resistant ground covers or covers over staging to catch the stripper/paint mixture. Polyethylene sheeting is usually sufficient. To protect the soil from contamination, a ground cover of substantial material is needed, as picking up the sludge-like waste may cause simple thin ground covers to rip. A means for collecting the water during the flushing/scrubbing stages is also needed. This may be more involved than first thought, as catching the waste water may not be a simple task. Indications are that ventilation systems will most likely not be needed for chemical stripping operations, and the level of sealing of joints and entryways may not have to be tight.

Worker exposure for chemical stripping is reported by OSHA to vary from 0.4 to 476 $\mu g/m^3$ with an average of 11 for 296 observations.(25) As the amount of lead in the paint for these observations is unknown, it is assumed that removal of lead-based primer systems resulted in the higher levels of worker exposure. Therefore, exposure will most likely be above the PEL, requiring the full program as described in the standard, albeit that a half-mask respirator with HEPA filters will most likely be all that is necessary for respiratory protection.

The waste from using alkaline strippers may be classified as a hazardous waste based on its corrosivity, if its pH is equal to or greater than 12.5. The waste from removing lead-based paints has a high probability of being classified as a hazardous waste due to its lead toxicity. Lead compounds have increased solubility in alkaline solutions. The lead goes into solution and cannot be removed by filtering. The amount of solid waste generated is about one barrel per 93 m^2 (1,000 ft^2).

WET ABRASIVE BLASTING

Abrasive blasting with water injection consists of adding water to the abrasive stream.(49) The water can be added externally or internally to the blast nozzle. External addition of water is accomplished using a water ring that is attached to the end of the blast nozzle. Internal addition is accomplished with equipment that either adds the water just prior to the blast nozzle (radially or coaxially), or by other specialized equipment that creates a water/abrasive slurry. Radial water injectors typically use 11.4 to 19 L/min (3 to 5 gal/min (GPM)), coaxial water injectors use 2 to 4 L/min (0.5 to 1 GPM), and slurry blasters use about 2 to 15 L/min (0.5 to 4 GPM).

As with dry abrasive blasting, wet abrasive blasting removes paint, rust, and mill scale, and is capable of achieving high levels of steel cleanliness. It also imparts a surface profile into the steel. It can be used to clean complex shapes as well as flat surfaces. Wet abrasive blasting also has the advantage of removing soluble salts that accelerate corrosion reactions. Another advantage of wet abrasive blasting is in minimizing the dust generated. Productivity of wet abrasive blasting methods is equal to or just slightly less than dry abrasive blasting. However cleanup time is increased as wet abrasive and debris sticks to the steel surface and must be washed off, and is more difficult to pick up. Wet steel corrodes. Therefore, a rust inhibitor must be used. The rust inhibitor can either be added to the water or sprayed on the surface as a separate step. The rust inhibitor used must be compatible with the coating system that will be applied. The coatings manufacturer must be contacted to obtain this information.

While visible dust is certainly reduced by wet abrasive blasting, no data was found that quantified the level of particulates and lead that would escape the work area. It appears that the revised SSPC Containment Guide will recommend a fully sealed, ventilated containment when a very high level of environmental protection is desired; a fully sealed, unventilated containment when a high level of environmental protection is desired; and a partially sealed, unventilated containment when a moderate level of environmental protection is desired.

The containment system would be complicated by the need to capture the water. For units that use a low amount of water, i.e., 2 to 4 L/min (0.5 to 1.0 GPM), most of the water either evaporates or is taken up into the debris to form a sludge. However, removing the wet abrasive from the steel requires washing, which will generate additional water. This water must be contained and collected. This will require a watertight containment, especially for work in the air. There is very little field experience on the design of such containments on bridges.

No data could be found on worker exposure to lead for wet abrasive blasting. It would appear that the incorporation of water into the abrasive would wet the dust formed and reduce worker exposure to airborne lead, though it is not known if this reduced exposure would be below the PEL. An ingestion hazard would still exist. Worker safety with regards to working in an area with wet abrasive is another important consideration. Wet abrasive and debris gives poor footing and it is easy to slip. A safe, sturdy platform is needed.

Wet abrasive blasting generates large amounts of heavy debris, as there is no significant reduction in the amount of debris compared to dry abrasive blasting. There is a very high probability that the waste from removing lead-based coating systems will be classified as a hazardous waste. Any water that does not evaporate must also be disposed. Tests performed to date on wet methods of coating removal have shown that the water contains lead. However, if the water is filtered through a 5-μm filter, the lead level is reduced significantly to the point where the lead level in the water is below storm sewer limits. The fact that the lead can be removed by filtering shows that the lead is present in the water as insoluble, particulate matter.

Mixing steel grit with the abrasive is not an effective method of generating a non-hazardous waste as the steel will rust. At best, only very short-term stabilization will occur. A preliminary investigation of the addition of a proprietary additive to abrasive used for wet abrasive blasting resulted in a non-hazardous solid waste, but the water contained lead that could not be removed by filtering. The water was classified as a hazardous waste.

VACUUM BLASTING

Vacuum blasting is identical to dry abrasive blasting with localized collection of the debris through a shroud around the nozzle.(50,51) The shroud has a brush head that is held up against the surface. The abrasive impinges on the surface and the debris generated is carried away through a hose connected to the shroud to a container or recycling unit. As vacuum blasting is a form of abrasive blasting, rust, mill scale, and paint can be removed and a surface profile imparted into the surface.

Proper use of vacuum blasting requires intimate contact between the blast head and the surface. It works best on flat surfaces, with special brush attachments needed to do inside corners, outside corners, and edges. While surface preparation on irregular surfaces such as nuts and bolts can be performed, it requires twisting the head and breaking the seal of the shroud, thus defeating the purpose of vacuum blasting. As the head must be held perpendicular to the surface, about 1.2 m (4 ft) of clearance is needed to obtain a proper seal due to the size of the shroud and bendability of the blast hose. Configuration of the structure is an important consideration when evaluating whether or not vacuum blasting is a viable alternative. It is most applicable to girder bridges, though areas such as expansion joints, the back surfaces of the end diaphragms, and bearing assemblies would create a problem in maintaining an adequate seal.

Productivity of vacuum blasting is relatively slow. Job productivity is about 0.9 to 1.4 m^2/h (10 to 15 ft^2/h) on structural steel, with faster rates (about 1.9 to 2.8 m^2/h (20 to 30 ft^2/h)) possible on flat surfaces. Part of the reason for the lower productivity is that the distance between the end of the blast nozzle and the surface is fixed. This results in a relatively small blast pattern. Going to a larger nozzle size to increase productivity results in a head assembly that is heavy and difficult to handle. Productivity is also a function of operator fatigue from the resistance of the brush head/vacuum system, and the need to rework areas as the blaster cannot see the results of his/her efforts until the head is removed from the work area. With time, the operator gains experience and knows how far to move the head between passes.

Proper use of vacuum blasting equipment does improve job productivity, as cleanup of the debris is accomplished as the work proceeds. Therefore, either more hours of productive blasting can be performed or additional workers usually needed for collection and cleanup do not have to be added to the project crew.

Containment requirements for vacuum blasting are very low. Technically, containment is localized at the head of the tool so no additional containment should be necessary. Practically, a small amount of abrasive or debris escapes when blasting is halted, and a small slug of debris falls to the ground. Also, dust and debris will escape whenever the seal between the shroud and substrate is broken. This occurs when attempting to clean complex shapes, or when the operator twists the head or pulls it away from the surface. In most cases, ground tarps under the work area will be sufficient to catch the large particulates. On structures with complex shapes, some side tarps may also be needed.

Worker exposure to lead is greatly minimized when vacuum blasting is performed correctly. OSHA made four observations of vacuum blasting and found the worker's exposure to vary between 2 and 665 $\mu g/m^3$ with an average of 169 $\mu g/m^3$.(25) Improper use of vacuum blasting would result in exposures closer to those seen with open abrasive blasting. Half-mask respirators with HEPA filters would appear to be sufficient respiratory protection if vacuum blasting were performed properly.

The amount of waste generated depends upon the abrasive used. The recyclability factor is reported as 3 to 7 times for coal slag, garnet, and aluminum oxide, and 600 to 700 times for steel grit.(52) The waste generated from removing lead-based paints using steel abrasive has a high probability of generating a non-hazardous waste. The long-term stability of this waste has already been discussed in this report. Debris from removing lead-based paints with coal slag, aluminum oxide, and garnet will have a high probability of being classified as a hazardous waste. No information could be found on the use of abrasive-blast additives in conjunction with vacuum blasting to generate a non-hazardous waste.

WATER BLASTING

Water blasting is a method of surface preparation where pressurized water is used to perform the cleaning.(53) A number of different systems are available, each with its own capabilities. National Association of Corrosion Engineers (NACE) has developed a classification system for water-cleaning methods based on the pressures used. These are:

- Low-pressure water washing (up to 350 kgf/cm^2 (5,000 lbf/in^2)).
- High-pressure water cleaning (350 to 700 kgf/cm^2 (5,000 to 10,000 lbf/in^2)).
- High-pressure water jetting (700 to 1750 kgf/cm^2 (10,000 to 25,000 lbf/in^2)).
- Ultra-high-pressure water jetting (above 1750 kgf/cm^2 (25,000 lbf/in^2).

Low-pressure water washing is intended for removing dirt, grime, soil, and foreign matter. High-pressure water cleaning also removes loose rust, loose coating, and loose mill scale. High-pressure water jetting and ultra-high-pressure water jetting can remove all paint, but will not remove mill scale or impart a surface profile into the steel. Either type of unit can achieve a final surface similar in definition to a Commercial Grade Cleaning (SSPC-SP6) except that mill scale will remain on the surface. Ultra-high-pressure units are recommended to achieve an appearance similar to a Near-White (SSPC-SP10) or White Metal (SSPC-SP5) Grade. Pressures greater than 2500 kgf/cm^2 (35,000 lbf/in^2) are needed to remove tightly adherent mill scale, but the rate of removal is extremely slow and not practical.

The productivity of these units is dependent on a number of factors, including type and condition of the existing paint, and maintaining the proper distance from the surface. High-pressure water cleaning is usually performed with the nozzle held about 5 to 25 cm (2 to 10 in) from the surface. Water-jetting units are usually most effective when held 0.6 to 1.3 cm (0.25 to 0.5 in) from the surface. The energy of the water, hence productivity, drops dramatically with distance from the surface. Maintaining the proper standoff distance is critical. Water-jetting units are most productive when the head is perpendicular to the surface. As the lance is usually a few feet long, it is difficult or impossible to use the equipment in tight spaces. Configuration of the structure should be investigated before considering the use of this method. Water units require about 4 to 57 L/min (1 to 15 GPM) of water, with the ultra-high-pressure units requiring the least amount of water. The more water used, the greater the thrust, and hence, the greater the operator fatigue. When properly used, the production rate of ultra-high-pressure water-jetting units is approximately one-third to one-half the production rate of dry abrasive blasting to achieve the equivalent of a Near-White (SSPC-SP10) level of cleanliness, though the mill scale is not removed nor is an anchor profile generated.

Water-cleaning methods are most useful when chemical contaminants such as salt are present in the steel. Removing these contaminants extends the life of a coating system. The evidence suggests that pressurized water methods are effective at removing salts.(54) As water-jetting methods cannot effectively remove mill scale nor roughen the surface, they are more appropriate for situations where it is known that the steel surface had been previously blast cleaned. Rust inhibitors must be used when cleaning to bare metal. The coatings manufacturer must be consulted to determine if the coating material is compatible with the rust inhibitor. Some rust inhibitors may not comply with local water regulations. This must be investigated prior to preparing the specification.

Containment requirements for water-blasting methods are mainly for controlling and catching the water and paint chips generated during cleaning. Very little dust is generated by these processes, so extensive containment to not exceed NAAQS does not appear to be warranted. As the water suppresses any dust generated, worker exposure is lowered, and a ventilation system is not usually used on the containment. In environmentally sensitive areas or areas of public access nearby, fully sealed joints and an overlap entryway would appear to be adequate. The difficulty with construction of containment would be catching and retaining the water generated. A watertight floor would be needed for containments constructed in the air. A method for containing and handling the water would be needed for containments that extended to the ground.

No data could be found on worker exposure to lead when performing water blasting. One controlling factor would be the pressure range being used. Low-pressure water washing would most likely result in very low exposures, most likely below the PEL. Higher pressures, especially those that remove all the coating, would be expected to produce higher levels of exposure.

The waste generated will consist of water and paint chips. No additional materials such as abrasives are used, so the amount of solid waste would be minimal. The amount of solid waste generated would be 310 to 920 gm/m^2 (1 to 3 oz/ft^2). The solid waste has a high probability of being classified as a hazardous waste when lead-based coating systems are removed. Local regulations may require retaining and testing the water prior to disposal. As the lead is present as solid particulates and is not soluble in neutral pH waters, filtering of the water should be sufficient. The filtered water could be reused for the water blasting and not disposed until the project is completed.

If the water must be retained and tested before either reuse or disposal, then provisions must be made for retaining the water. As the units use 4 to 57 L (1 to 15 gal) of water per minute, depending upon manufacturer, the amount of water needed (and waste water generated) would be between 1140 to 20 400 L/day/unit (300 to 5,400 gal/day/unit). Depending upon how quickly laboratory analysis results can be obtained, several days accumulation may need to be retained. Containers will be needed to hold significant quantities of water. If the filtered water must be held until the laboratory results are available, the container requirement increases.

WATER BLASTING WITH ABRASIVE INJECTION

Water blasting with abrasive injection consists of a water-blasting unit with the abrasive injected into the water stream near the nozzle.(53) The purpose of the abrasive is to increase productivity, remove tightly adherent contaminants such as mill scale, and to impart a surface profile into the surface. Production rates are intermediary between the water-blasting method used and dry abrasive blasting, or about 75 percent of the rate of dry abrasive blasting. The method is fairly effective on complex shapes and hard to reach areas, as there is significant contribution to cleaning from the abrasive. The operator must have sound, safe footing as wet abrasive and debris are quite slippery. Swinging stages and bosun chairs would not be acceptable scaffolding. Therefore, water blasting with abrasive injection, as abrasive blasting with water injection, is not applicable to all structures. Expendable, rather than recyclable, abrasives are used. As this is a wet method, a corrosion inhibitor is required.

Water blasting with abrasive injection uses about one-quarter of the amount of abrasive compared to dry abrasive blasting. Therefore, the amount of waste generated is significantly reduced compared to dry abrasive blasting. The waste from removing lead-based paints has a high probability of being classified as a hazardous waste. The water may also be a hazardous waste due to very fine particulates. Filtering the water through a 5-μm filter should remove those particulates, resulting in total lead levels in the water below any storm water sewer standards.

The use of water with the abrasive greatly reduces the airborne particulates. Table 21 presents air quality data comparing dry abrasive blasting to wet abrasive blasting. According to the information supplied, the same sand abrasive was used for both dry and wet abrasive blasting without any containment, and particulates were measured with a PM_{10} monitor. An over 80-percent reduction in particulate matter was obtained. The length of blasting and monitoring time were not reported. The data would indicate that the NAAQS for particulates of 150 $\mu g/m^3$ per 24 h would be exceeded to a distance of 61 to 150 m (200 to 500 ft) if no containment were used.

Containment would be required to limit air emissions as well as to collect the water and debris generated. It would be reasonable to assume that the lead in the air would be reduced by an amount similar to the reduction obtained for particulate matter, i.e., the PM_{10}. Therefore, the method would appear to have sufficient engineering controls to satisfy OSHA requirements. An additional ventilation system would not be expected to lower the concentration of lead to a level below the PEL. Containment walls would appear to be sufficient for removing airborne particulates so that NAAQS limits are not exceeded, though no data of actual measurements were found.

Table 21. Particulate measurements from dry and wet abrasive blasting.[1]

Distance from Blaster m (ft)	Particulate Matter ($\mu g/m^3$)		Percent Reduction
	Dry	Wet	
1.5 (5)	257 612	42 289	84
15 (50)	45 986	3271	93
30 (100)	6175	555	91
61 (200)	2708	323	88
150 (500)	898	191	79

[1] Data from White Metal Inc. Literature (1987).

POWER-TOOL CLEANING TO BARE METAL

Power-tool cleaning to bare metal is described by SSPC-SP11. The technique uses cleaning media attached to power tools to remove paint, rust, and mill scale. The final surface has an appearance similar to Commercial (SSPC-SP6) or Near-White (SSPC-SP10) metal blast. The method requires using a variety of cleaning media to achieve the end condition. The media includes surface-cleaning materials and surface profile-producing materials. Surface-cleaning materials include non-woven abrasive wheels and discs, sanding pads, coated abrasive flap wheels, coated abrasive bands, and other coated abrasive devices. Surface-profiling tools include rotary impact flap assemblies and needle guns equipped with 2-mm-diameter needles. SSPC-SP11 requires a minimum 25-μm (1-mil) surface profile. The choice of media is dependent upon the existing condition of the substrate. Surface-cleaning media may be sufficient if the steel has been previously blast cleaned, as long as the profile is not destroyed during the cleaning process. Both surface-cleaning and profiling media would be required if the original surface still contained mill scale. This will require multiple passes over the surface with different types of tools.

Power-tool cleaning to bare metal can be performed on complex shapes and hard to reach areas, provided the proper tool is used. A complete array of tools of different shape, size, and design are available to clean almost any surface. Unfortunately, the norm is usually to have a certain number and type of tools on the job and to try to use these tools for all surfaces, rather than obtaining the appropriate tool for the situation. Reported production rates range from 1.3 m^2/man-h (14 ft^2/man-h) to remove coating to a mill scale surface, 0.5 to 1.6 m^2/man-h (5 to 17 ft^2/man-h) for a surface approaching an SSPC-SP11, and 2.3 m^2/man-h (25 ft^2/man-h) to achieve an SSPC-SP11.(44-46)

Power tools can also be purchased with vacuum shrouds around the head of the tool. The shroud assembly is attached to a vacuum line that transfers the debris generated back to a collection vessel. Depending on the manufacturer of the equipment, this vessel can be as large as a 208-L (55-gal) drum, or as small as a unit that can be carried as a backpack (23 L (6 gal)). The air exiting the collection vessel is equipped with a high-efficiency particulate filter (HEPA) as required by OSHA.

The method of obtaining the seal between the tool and the surface varies by tool type. In some cases, it is a hard shroud, and in other cases, it is a brush-head assembly. As with vacuum blasting, the seal of the shroud is best on flat surfaces or with shrouds configured to the work, i.e., corners and edges. The ability to clean complex shapes is limited due to the restrictions of the vacuum shroud. Productivity of vacuum-shrouded power tools is similar to use of the tools without the shrouds.

Waste generation, impact on air quality and worker exposure, and containment requirements have previously been discussed under hand- and power-tool cleaning.

OTHER CLEANING METHODS

Other blasting methods are commercially available, but have had limited use in lead-paint removal to date. These methods are sodium bicarbonate blasting, sponge blasting, and carbon dioxide blasting. Even newer technology under development are laser cleaning and robotics.

Sodium Bicarbonate Blasting

Sodium bicarbonate, or baking soda, is formed into pellets of abrasive size and is used as a cleaning media. It is used with wet abrasive blasting equipment. After impinging on the surface, the sodium bicarbonate pulverizes and dissolves in the water. Sodium bicarbonate is relatively soft. Therefore, it is capable of removing only the paint. Expendable abrasives such as mineral sands or slags can be mixed in with the sodium bicarbonate when it is necessary to remove mill scale and rust. Addition is about 15 percent by weight. Containment for sodium bicarbonate blasting is similar to that required for water blasting. If another abrasive is added to the sodium bicarbonate, then the discussion on wet abrasive blasting would apply. Other concerns, such as collection of the water for testing prior to disposal apply to this method.

The amount of waste generated is small when sodium bicarbonate alone is used, as there is no contribution from the abrasive. The sodium bicarbonate dissolves in the water. The waste would most likely be classified as non-hazardous, due to residues of sodium bicarbonate mixed in or on the paint chips. It is known that lead-containing wastes treated with sodium bicarbonate generate a non-hazardous waste due to pH control during the TCLP extraction. However, there would be no long-term stability to the waste in a landfill, as water percolating through the mass would eventually dissolve any residual sodium bicarbonate coating the particles. The waste should be considered to be similar to paint chips obtained from water blasting.

Sponge Blasting

Sponge blasting uses a special sponge media to perform the cleaning.(55) Different sponge-blast media are available. Straight sponge is only effective for removing paint. Other blasting media have the sponge formed around different types of abrasive particles, such as mineral sand, garnet, or steel grit. These media are capable of removing rust and mill scale, achieving a final surface that meets the SSPC definitions, i.e., Commercial (SSPC-SP6), Near-White (SSPC-SP10), and White Metal (SSPC-SP5). Sponge blasting does require specialized equipment. The abrasive is fed with a screw-feed mechanism rather than with a blast pot. The abrasive is also recyclable.

Less dust is generated when sponge or sponge-coated abrasives are used, especially when dampened. It is thought that the fine dust particles are adsorbed or absorbed by the sponge. It was found on one job, where personal air monitoring was performed, that blasters were exposed to less lead than workers involved in cleanup and recycling of the media.(56) Limited information is available about production rates. It has been reported by the manufacturer that the production rate for sponge-covered steel grit media is about the same as dry abrasive blasting with coal slag, and about 50 percent of that for the sponge-covered garnet. The waste generated from removing lead-based paints has a high probability of being classified as a hazardous waste. Assuming the abrasive can be recycled five times, the amount by weight (volume higher) of waste would be approximately 20 percent of the waste generated by dry abrasive blasting with an expendable abrasive.

Carbon Dioxide Blasting

Carbon dioxide, or dry ice, is formed into pellets and used as the blasting media. Dry ice sublimates at room temperature, which means it goes from a solid to a gas without becoming a liquid. Thus, the spent abrasive pulverizes and then vaporizes upon blasting. Carbon dioxide is a soft material. It is thought that the cold temperatures of the dry ice contribute to the cleaning process in some manner by cooling the surface. Either the coating becomes more brittle or thermal shock contributes to the removal process. Carbon dioxide blasting only removes the paint, and will not remove rust and mill scale, nor impart a surface profile into the steel. Complete removal of the paint is very difficult and/or time-consuming. Going over the surface in a productive manner leaves thin areas or traces of the old primer. Attempting to remove all traces of old paint is either extremely slow or cools the surface to below the dew point so that condensation and icing occur. Production rates are about 2 to 2.8 m^2/h (20 to 30 ft^2/h) to remove the paint to the condition described above.

Carbon dioxide blasting requires specialized equipment. Carbon dioxide is delivered in liquid form. A nearby source of liquid carbon dioxide is needed to keep the unit supplied. The liquid carbon dioxide is frozen, extruded, and crushed into abrasive-size particles. Blasting is performed with a special nozzle. High blast pressures over 0.14 kgf/cm^2 (over 200 lbf/in^2) are preferred. This requires air compressors larger in size than normally used in abrasive blasting.

The paint particles removed by the process are larger than what is achieved with dry abrasive blasting, and the amount of dust is reduced. This lowers worker exposure and the probability of exceeding NAAQS limits. The waste generated by the process is minimal, as it only consists of paint chips, loose rust, and loose mill scale. The probability of generating a hazardous waste is very high when lead-based coating systems are removed.

Laser Cleaning

Laser cleaning uses pulses of high-intensity light to remove the coating. The vapors and fumes are collected with a vacuum system. The technique removes only the coating and does not remove mill scale or rust. Laser-jet cleaning was originally developed for removing aircraft coatings. FHWA, in cooperation with the U.S. Army Corps of Engineers, sponsored a research project that successfully demonstrated the feasibility of using a laser to remove bridge paints. A prototype unit with an expected capability of removing the coating at 9.3 m^2/h (100 ft^2/h) is scheduled for field trials on bridges in spring 1994.

Robotics

Robotics consists of dry abrasive blasting with an automated system.(57) The unit consists of multiple-blast nozzles attached to a frame that rides on the lower flanges of the girders. The unit is operated by remote control or can be programmed for automatic operation. The frame makes multiple passes down the length of the girder between obstructions, i.e., piers or diaphragms. The angle of the blast nozzles is changed with each pass, thus blast cleaning the entire surface of the girder. Items such as diaphragms and bracing members will not be cleaned, which will have to be performed manually, as will any spot touchup. The purpose of robotics is to minimize lead exposure to workers by removing them from the work area. Workers would be removed from the immediate work area when high levels of lead are generated for the majority of the time when surface preparation is being performed.

The use of robotics with water jetting and vacuum blasting has also been reported.(57) Automatic operation of equipment would appear to have economic advantages by reducing labor costs. Another attribute would be more consistent quality. The challenge is in developing a system that can be used or adapted to highway bridges.

VIII. COST

GENERAL

Evaluating and developing cost information is not a simple task. A number of factors will affect cost, such as local labor rates, materials costs, and disposal costs, such that the exact same project in different parts of the country will have different costs. A common method for developing a cost estimate for a coating project is based on surface preparation costs, paint-application costs, and materials costs. These costs are then multiplied by a difficulty factor depending on height and intricacy of the structure. This factor is between 90 percent (simple, easily reached structures) and 150 percent (intricate structures or structures over 15 m (50 ft) high. Further refinement of surface preparation cost can be made based on the initial condition of the surface. Using this method with 1992 cost data for field painting, the estimate for blast cleaning to a Near-White Metal (SSPC-SP10) and applying a three-coat painting system would be:(58)

Surface Preparation		\$10.80/m^2 (\$1.00/ft^2)
Paint Application		\$ 9.70/m^2 (\$0.90/ft^2)
Materials (Paint)		\$ 3.80/m^2 (\$0.35/ft^2)
	Total	\$24.30/m^2 (\$2.25/ft^2)

The installed cost for this coating system, therefore, would be between \$21.50 and \$43.00/m^2 (\$2 and \$4/ft^2).

The above cost estimate assumes that containment was not used, the debris was not collected, environmental monitoring was not performed, and no special worker protection requirements were followed. These added items have increased the cost significantly.

ABRASIVE BLASTING

Reported costs for bridge-painting projects performed in compliance with the existing regulations at the time have varied greatly. Medford reported costs of \$28.5/m^2 (\$2.65/ft^2) and \$30.46/m^2 (\$2.83/ft^2) for two projects in North Carolina requiring an SSPC-SP6 level of cleanliness and application of a four-coat, oil-based paint system.(38) Both projects required a negative-pressure containment system. The cost of the first project included traffic control also. Neither project included waste disposal. Ohio DOT is reported to have paid \$53.80 to \$64.80/m^2 (\$5.00 to \$6.00/ft^2) for projects requiring total containment with screens (no negative pressure), an SSPC-SP10 level of cleanliness, and an organic zinc/epoxy polyamide/polyurethane painting system.(59) Bid prices rose to \$108 to \$150/m^2 (\$10 to \$14/ft^2) when recycled abrasive was required, which dropped to about \$86.10/m^2 (\$8.00/ft^2) with time. Lyras has reported the cost of abrasive-blasting projects from an estimating program for varying situations as shown in table 22.(60,61) Comparison of the data in the literature is difficult, as each article includes different factors in developing their costs.

Table 22. Cost estimates of abrasive-blasting projects.[1]

Cost per m^2 (ft^2)			
Option	Blasting Productivity m^2/nozzle/day (ft^2/nozzle/day)		
	18.6 (200)	37.2 (400)	56 (600)
Sandblasting with no disposal[2]	\$80.70 (\$7.50)	\$45.75 (\$4.25)	\$37.70 (\$3.50)
Sandblasting with disposal[2]	\$64.50 (\$6.00)	\$35.00 (\$3.25)	\$24.22 (\$2.25)
Steel abrasive with disposal[2]	\$67.25 (\$6.25)	\$35.00 (\$3.25)	\$24.22 (\$2.25)
Negative-pressure containment over water[3]	\$137.80 (\$12.80)	\$86.10 (\$8.00)	\$78.90 (\$7.33)
Total containment, no negative pressure, over water[3]	\$126.37 (\$11.74)	\$80.75 (\$7.50)	\$75.35 (\$7.00)
Total containment, no negative pressure, over land[3]	\$101.93 (\$9.47)	\$64.50 (\$6.00)	\$62.43 (\$5.80)

[1] Data extrapolated from references 60 and 61.
[2] Overpass bridge; overhead included, but no profit; blast, and prime.
[3] No overhead or profit; blast, and three coats of paint.

The cost of an abrasive-blasting project can be subdivided as follows:

	Range \$/m^2 (\$/ft^2)	Average \$/m^2 (\$/ft^2)
Cleaning & Painting	21.50 - 43.00 (2 - 4)	27.00 (2.50)
Containment	10.75 - 54.00 (1 - 5)	21.50 (2.00)
Disposal	0 - 32.00 (0 - 3)	5.40 (0.50)
Environmental Monitoring	0 - 21.50 (0 - 2)	5.40 (0.50)
Worker Health	10.75 - 21.50 (1 - 2)	16.15 (1.50)
Overhead/Miscellaneous	0 - 21.50 (0 - 2)	5.40 (0.50)
Total	43.00-193.50 (4 - 18)	80.85 (7.50)

Each of these cost elements is discussed below.

Cleaning and Painting (Expendable vs. Non-Expendable Abrasives)

The range of cost in the cleaning and painting item will be affected by the level of cleanliness specified, coating system, type of structure, local labor rates, condition of the coating, etc. as previously mentioned. Of interest is the cost difference between the use of recycled, steel-grit abrasive and an expendable abrasive such as slag or mineral sand. Any cost differences are related to equipment and abrasive costs, and disposal costs. All other costs, such as containment, worker health, and environmental monitoring, would be identical. Though contractors have reported that productivity increased with the use of steel abrasive, an evaluation performed during this project did not find a significant difference in the production rate between the steel and mineral sand abrasive used at 698-kPa (100-lbf/in^2) pressure at the nozzle.

There is a significant difference in the cost of abrasive. Expendable abrasives cost between $27.50 to $110/t ($25 to $100/ton), while steel grit costs between $330.50 to $496/t ($300 to $450/ton). An average cost of $66/t ($60/ton) and $441/t ($400/ton), respectively, were used for the calculation. Approximately 39 to 59 kg/m^2 (8 to 12 lb/ft^2) of slag abrasive are required to achieve an SSPC-SP10 level of cleanliness. Steel has a density about twice that of slag, but also requires less abrasive per unit area. Based on the results of the research, the same weight of abrasive is used per unit area, or 39 to 59 kg/m^2 (8 to 12 lb/ft^2). Notwithstanding the number of times the steel can theoretically be recycled, a realistic estimate of the amount recovered derived from the data of Olson and Burbank is 95 percent (though higher recovery should be possible).(41) Therefore, 5 percent or 2 to 3 kg/ft^2 (0.4 to 0.6 lb/ft^2) will be consumed. Abrasive cost, therefore, is $0.86 to $1.30/m^2 ($0.08 to $0.12/ft^2) for steel grit and $2.73 to $4.13/m^2 ($0.24 to $0.36/ft^2 for slag abrasive.

Though the cost of abrasive consumed per unit area is less for recyclable steel grit, there are added equipment and operation costs. Information from suppliers indicates that the rental cost of a recycling unit capable of supporting three or four blasters is $12,000 to $18,000 per month. This includes the recycling unit, dust collector, and air drier, i.e. equipment normally not used when blasting with slag abrasive. Assuming the equipment is used for 20 days per month, the daily equipment charge, based on $15,000 per month, would be $750 per blasting day. Adding in operating costs (fuel, maintenance, etc.) of $100/day, and an operator ($25/h for 8 h) gives a total cost of $1,050 per blasting day.

The cost per unit area depends upon production rate. Table 23 presents calculations of the differential cost based on the amount of surface area cleaned in a day. As the production rate for the scenario chosen on most bridge projects is 139 to 232 m^2 (1,500 to 2,500 ft^2), the added cost for the actual surface preparation using steel abrasive compared to slag abrasive is calculated to be $2.37 to $5.38/m^2 ($0.22 to $0.50/ft^2). There will be a cost savings for recycled steel abrasive based on disposal cost, which is discussed below.

Containment

Dry abrasive blasting will require use of a containment incorporating a ventilation system (Class 1, 2, or 3 in SSPC Guide 6I (CON)). Barnhart reports the average bid for containment for 8 Ohio DOT contracts consisting of 31 bridges to be $16.25/m^2 ($1.51/ft^2).(61) This information was judged to be the most reliable and was modified to account for recent changes in regulations. Ohio DOT containment requirements consisted of unventilated, full containment using 85-mesh screen. As the OSHA Construction Industry Lead Standard will require the use of ventilation, solid tarps must be used and dust collection equipment must be included in the cost.

The research has indicated that the cost difference between solid tarps and mesh screens is minimal, but there will be an added cost of about 5 to 10 percent to obtain adequate seals. The biggest cost increase will be for the ventilation.

Large dust collectors, such as the type needed on bridge projects for the ventilation system, cost between $25,000 and $100,000, depending on size. A 566.3-m^3/min (20,000-CFM) dust collector costs about $70,000. Assuming a monthly rental of 10 percent of the purchase price gives $7,000 a month. Operating expenses (fuel and maintenance) are $4 to $5/h, giving an hourly rate close to $50/h. Using the assumption that the target-blasting production rate is 139 to 232 m^2/crew-day (1,500 to 2,500 ft^2/crew-day), the cost of the ventilation system will be in the range of $1.62 to $2.70/$m^2$ ($0.15 to $0.25/$ft^2$). Using Ohio DOT's cost experience and adding in the estimated cost of the increased containment and ventilation system gives an estimated cost of $21.50/$m^2$ ($2.00/$ft^2$).

Table 23. Differential cost of abrasive and recycling for recyclable steel compared to slag.

Production Rate m^2 (ft^2)/ crew-day	Steel $/$m^2$ ($/$ft^2$)			Slag $/$m^2$ ($/$ft^2$)	Premium for Steel Abrasive $/$m^2$ ($/$ft^2$)
	Abrasive	Operation	Total	Abrasive	
93 (1,000)	1.08 (0.1)	11.30 (1.05)	12.38 (1.15)	3.23 (0.3)	9.15 (0.85)
140 (1,500)	1.08 (0.1)	7.50 (0.70)	8.61 (0.80)	3.23 (0.3)	5.38 (0.50)
186 (2,000)	1.08 (0.1)	5.70 (0.53)	6.78 (0.63)	3.23 (0.3)	3.55 (0.33)
232 (2,500)	1.08 (0.1)	4.50 (0.42)	5.60 (0.52)	3.23 (0.3)	2.37 (0.22)
280 (3,000)	1.08 (0.1)	3.77 (0.35)	4.84 (0.45)	3.23 (0.3)	1.08 (0.10)

DISPOSAL

A number of scenarios are possible and a number of different options have been discussed in this report. These include:

- Expendable abrasive (non-hazardous waste).
- Expendable abrasive (hazardous waste).
- Expendable abrasive with steel additive (hazardous waste).
- Expendable abrasive with proprietary additive (non-hazardous waste).
- Expendable abrasive with steel additive and portland cement stabilization (non-hazardous).
- Expendable abrasive with proprietary additive and portland cement stabilization (non-hazardous).
- Recyclable steel abrasive (hazardous waste).
- Recyclable steel abrasive and portland cement stabilization (non-hazardous waste).

Waste-disposal costs will depend on the amount of debris generated per unit area and waste classification. The disposal cost of hazardous waste varies between \$276 to \$496/t (\$250 to \$450/ton), depending on the amount of waste and how it is packaged. The disposal cost of non-hazardous waste is about \$0.03 to \$0.09/kg (\$25 to \$80/ton), depending on local landfill charges. The cost of transportation will be extra.

In developing the cost estimates for the various options, it was decided to add all associated costs into disposal. Therefore, adding 10 percent steel grit into an expendable abrasive to generate a non-hazardous waste increases the cost of the abrasive. As the blasting quality of the steel abrasive used in this scenario is not important, cheaper steel abrasive at \$0.39/kg (\$350/ton) would be used, raising the price for the treated abrasive to \$0.09/kg (\$85/ton) from \$0.06/kg (\$50/ton). At a use rate of 39 to 59 kg/m^2 (8 to 12 lb/ft^2), the added abrasive cost considered in disposal is \$1.51 to \$2.26/m^2 (\$0.14 to \$0.21/ft^2), with a median cost of \$1.94/m^2 (\$0.18/ft^2). Information from abrasive suppliers indicates that cost of a proprietary additive preblended with a slag abrasive is \$0.11/kg (\$100/ton) for materials and blending, or \$5.40/m^2 (\$0.50/ft^2) based on a consumption rate of 49 kg/m^2 (10 lb/ft^2).

A cost estimate of \$0.07/kg (\$65/ton) of debris for onsite stabilization with portland cement was developed based on the Kansas DOT formulation using the following rates:

Mixer rental	\$200/wk
Waste treated	27 216 kg (30 tons)/wk
Labor	\$1,000/wk
Cement	\$3.00/sack

The cost for the various disposal options are presented in table 24. The cost of onsite Portland cement stabilization with disposal in a hazardous waste landfill was not calculated, as this option would be illogical. Regulations require stabilization of hazardous waste before landfill disposal, which is included in the cost of disposal by hazardous waste landfills. A landfill charge of \$0.03/kg (\$25/ton) for non-hazardous waste was used in the calculation. The charge for hazardous waste was \$0.28/kg (\$250/ton) for slag options, and \$0.50/kg (\$450/ton) for recyclable steel, as the slag would be most economically shipped in large lots while the recyclable steel would be packaged in drums. Container costs and transportation costs were not considered in the calculation. It was also assumed that the weight of abrasive represented the amount of debris, i.e. the added weight of abrasive represented the amount of debris with the added weight of paint and rust was equal to the amount of debris lost.

The disposal cost for a non-hazardous waste using slag abrasive was \$1.40/m^2 (\$0.13/ft^2). However, the probability of generating a non-hazardous waste from removing lead-based paints from bridges is quite small. Onsite stabilization of hazardous waste and disposal of the cement blocks is about one-third the cost of direct disposal in a hazardous waste landfill, but does require submission of a waste analysis plan to U.S. EPA.

The use of 10 percent steel to expendable abrasive, onsite portland cement stabilization and disposal as a non-hazardous waste is about one-half the cost of no additive and disposal as a hazardous waste. The cost of using a steel additive and disposal as a non-hazardous waste was not included in table 24, as the experiments performed in this project showed the combination did not have long-term stability.

Recyclable steel abrasive, though usually generating a non-hazardous waste initially, does not have long-term stability. Disposal as a hazardous waste is recommended. This was estimated to cost \$1.18/m^2 (\$0.11/ft^2). The calculated price for portland cement treatment and disposal as a non-hazardous waste was \$0.32/m^2 (\$0.03/ft^2). This cost is probably low as the values used in the calculation contained some economy of scale based on stabilizing large quantities of debris. Also, further research and testing is needed to develop the proper mixture design.

In comparing the cost of disposal of recyclable abrasive to expendable abrasive, the preferred alternatives based on technical considerations and cost are disposal of the recyclable steel abrasive as a hazardous waste and use of steel grit and portland cement stabilization for expendable abrasives. The disposal costs associated with recyclable steel abrasive were \$6.14/m^2 (\$0.57/ft^2)—less expensive than the disposal cost for expendable abrasive. Comparing this savings to the premium cost calculated for blasting with recyclable steel abrasive (table 23) shows the project cost to be comparable, or less, for recyclable steel abrasive.

Table 24. Cost of disposal.

Option	Post-Method Stabilization	Disposal Cost \$/m^2 (\$/ft^2)	
		Non-Hazardous Waste	Hazardous Waste
Slag abrasive	none	1.40 (0.13)	13.39 (1.30)
	portland cement	5.38 (0.50[1])	---
Slag with steel	none	---	15.93 (1.48)
	portland cement	7.32 (0.68)	---
Slag with proprietary	none	6.78 (0.63)	15.50 (1.44)
	portland cement	10.33 (0.96)	---
Recycled steel abrasive	none	---	1.18 (0.11)
	portland cement	0 .32 (0.03)	---

[1] Requires Waste Analysis Plan for onsite treatment if the waste is considered hazardous.

Environmental Monitoring

Environmental monitoring is another cost that must be included in the cost calculation. This includes air monitoring and soil sampling. Different strategies can be used for air monitoring, including monitoring during the duration of the job; monitoring for the first week on a regular basis, i.e., every few months; monitoring only in cases of complaint; or no air monitoring. Air monitoring to meet NAAQS requirements must be performed with a minimum of two sets of high-volume air monitors. One of the monitors, a PM_{10}, is used for measuring particulate matter, and a Total Suspended Particulates (TSP) monitor is used to measure lead. A technician is needed to calibrate the monitors, change the filters, and maintain the monitors. A source of power is needed, which is usually a portable generator. The availability of high-volume air monitors is limited and firms owning such monitors are not widespread. Therefore, there are mobilization/demobilization expenses involved with air monitoring, as well as living expenses for the technician. When all these charges for soil sampling and laboratory analyses are included, the price for environmental monitoring comes to approximately \$5,000 to \$10,000/week. Using the typical production rate of 139 to 232 m^2/crew-day (1,500 to 2,500 ft^2/crew-day), the cost for environmental monitoring is estimated to be in the range of \$4.30 to \$14.32/m^2 (\$0.40 to \$1.33/ft^2). The average cost per project is estimated at \$5.38/m^2 (\$0.50/ft^2) as continuous monitoring is generally not performed.

Worker Health

Worker health costs are difficult to estimate since the OSHA Construction Industry Lead Standard just became law. Under this regulation, contractors must provide workers with protective clothing, mandated respiratory protection, and shower/decontamination facilities. They also must supply each worker with medical examinations, respirator fit tests, and regular blood analysis for lead and ZPP. Worker training and written compliance programs are other costs that must be recouped. According to OSHA, the cost of compliance is estimated to be \$3,625 per worker for bridge, tunnel, and elevated highway workers. Assuming a five-person crew blast cleans 18 600 m^2/yr (200,000 ft^2/yr), this translates to \$0.97/m^2 (\$0.09/ft^2). This estimate is obviously very low. A decontamination trailer with two showers, for example, rents for \$2,000/month, or \$100/blasting day. For a cleaning rate of 140 m^2 (1,500 ft^2)/crew-day, the decontamination trailer alone, costs \$0.75/m^2 (\$0.07/ft^2).

A major cost increase comes from lost productivity. Contractors have reported 1 to 2 hours in lost productivity due to washing, cleaning, and showering requirements for the worker. This is about 15 percent of the work day. Based on an average cleaning and painting cost of \$27/m^2 (\$2.50/ft^2), the cost of the lost time is \$4.09/m^2 (\$0.38/ft^2). Meeting OSHA regulations also requires extra work in maintaining a clean work area, writing and maintaining compliance programs, performing respirator fit tests, etc. Some of these functions must be performed by onsite personnel, while other functions are performed by corporate personnel such as the Safety Director. The best estimate that can be made for these expenses is by adding an extra person to the crew. Going from a five-person crew to a six-person crew is a 20 percent increase, which is another \$5.40/m^2 (\$0.50/ft^2) increase for a total of \$9.47/m^2 (\$0.88/ft^2). Cost must also be added for exposure monitoring, medical monitoring, training, protective clothing, change trailers, etc. The best estimate is that this will increase the cost for worker health requirements an extra 50 percent, or \$14.2/m^2 (\$1.32/ft^2). The best estimate, therefore, is that the cost of OSHA compliance will be in the range of \$10.76 to \$16.15/m^2 (\$1.00 to \$1.50/ft^2) for a typical project.

Overhead/Miscellaneous

Overhead and miscellaneous costs have also been included in the calculation. The most notable added item is pollution insurance. Pollution insurance recently advertised was $25,000 per site. If a typical overpass bridge has 9290 m^2 (100,000 ft^2), the cost would be \$2.70/m^2 (\$0.25/ft^2). There is also increased overhead due to recordkeeping functions, especially for OSHA compliance, where employee medical records, air-monitoring results, and other information must be maintained. Lead projects sometimes also require added attention from central office staff. Field staff may not be sufficiently knowledgeable on some health and environmental issues and technical assistance or involvement of overhead staff will be required. The best estimate that can be made is to double the cost of pollution insurance to \$5.38/m^2 (\$0.50/ft^2).

OTHER SURFACE PREPARATION METHODS

The cost of other surface preparation methods are presented in table 23. Costs have been presented in the same form as presented for abrasive blasting. Results from all the methods tested, including chemical stripping and vacuum-shrouded power tools, showed that the PEL for lead was exceeded. Therefore, the cost for worker health would be the same, no matter what surface preparation method was used. At this time, the requirements for environmental monitoring, especially air monitoring, cannot be ruled out for any surface preparation method. Therefore, this cost is also included in determining the average cost. Overhead/miscellaneous costs are also considered to be the same for all surface preparation methods, as the main component of this item is pollution insurance.

Wet Abrasive Blasting

While the production rate of wet abrasive blasting is similar to or only slightly less than dry abrasive blasting, the cost to do the work will be more. The basic equipment costs are the same, but some increase will result from a water-addition system and corrosion inhibitor. For example, the flash rust inhibitor is estimated to cost \$0.54 to \$1.08/m^2 (\$0.05 to \$0.10/ft^2). The published estimate for slurry blasting is \$13.45/m^2 (\$1.25/ft^2), compared to dry abrasive blasting at \$10.76/m^2 (\$1.00/ft^2).(58) Using the average cost for dry abrasive blasting for comparative purposes, the average cost for cleaning and painting using wet abrasive blasting would be estimated to be about \$29.60/m^2 (\$2.75/ft^2). This would apply to ground structures or structures that are easily scaffolded. However, if work were performed in the air with marginal scaffolding, production rates would drop significantly as workers would be more concerned about footing. A 50 percent drop in productivity on a high structure would result in an estimated cost for surface preparation of \$27/m^2 (\$2.50/ft^2). Adding the cost of coating application and coating materials, and multiplying by the height difficulty factor gives an upper-range estimated cost for cleaning and painting of over \$70/m^2 (\$6.50/ft^2) for this situation.

The cost of containment is dependent upon type of structure and local regulations. Basic containment will consist of a tarp arrangement with partially sealed or fully sealed joints. A ventilation system would not be needed. For a ground-level structure where the water does not have to be collected, this containment would cost about \$2.70 to \$5.40/m^2 (\$0.25 to \$0.50/ft^2). A fully sealed containment of this sort would be about \$5.40 to \$8.07/m^2 (\$0.50 to \$0.75/ft^2). A basic containment constructed in the air would be about \$16.15/m^2 (\$1.50/ft^2).

Much more complex containment will be needed if it is necessary to collect the water for testing prior to disposal. Wet abrasive blasting units generally use very little water. The blasting process aids in breaking the water into fine particles and heating it, which promotes evaporation. Most of the water evaporates leaving a sludge. However, washing the debris from the surface uses much more water, which is not broken into fine particles and collects in puddles. There is very little field experience in containing water from wet abrasive blasting. For structures where the water can fall to the ground, layers of tarps and plastic sheeting would be sufficient. However, for work performed in the air, a leak-proof containment bottom must be constructed. The best estimate for this situation would be \$43.00 to \$64.50/m^2 (\$4.00 to \$6.00/ft^2).

Only expendable abrasives can be used with wet abrasive blasting. For the example of using 49 kg/m^2 (10 lb/ft^2) of abrasive, the cost of disposal of non-hazardous and hazardous waste would be \$1.00 to \$3.80/m^2 (\$0.10 to \$0.35/ft^2), and \$10.76 to \$27.00/m^2 (\$1.00 to \$2.50/ft^2), respectively. It is possible to use a proprietary additive with the abrasive, with a disposal cost of \$7.00 to \$9.15/m^2 (\$0.65 to \$0.85/ft^2). The cost of collecting the debris must be added to the disposal costs. It is more difficult to collect and move damp debris than dry debris. On a low structure such as a grade separation, washdown of the surface will result in all the debris being deposited on the ground cover. All that is required is scooping up the material and placing it in containers. The cost of collection of the debris in this situation would be approximately \$0.32/m^2 (\$0.03/ ft^2). However, for a high structure or a truss bridge with horizontal surfaces, the manpower to clean it could be significant. Labor charges could be equal to or more than paint application, especially if multiple washing steps are involved or debris must be manually removed. The cost estimate, therefore, is \$1.08 to \$5.38/m^2 (\$0.10 to \$0.50/ft^2).

Should the water need to be collected and disposed, the cost of disposal of the water must be included. The simplest method would be to filter the water through a 5-μm filter and dispose of it directly. A filtering apparatus costs about \$1,000 to \$2,000. Even with replacement filters, the cost to the project would only be a few cents per square foot. If the water must be disposed as a hazardous waste, the cost per drum would be \$1.20 to \$2.16/L (\$250 to \$450/drum). Assuming a gallon of water is used to clean 0.9 m^2 (10 ft^2), the disposal cost of the water would be \$4.84 to \$10.76/m^2 (\$0.45 to \$1.00/ft^2).

The range of costs for environmental monitoring, worker health, and overhead/miscellaneous would be the same as estimated for dry abrasive blasting. The cost of wet abrasive blasting would be only slightly greater than dry abrasive blasting for simple, low structures, such as a grade crossing. For elevated structures or situations where the water must be collected, retained, and tested prior to disposal, costs increase significantly.

Table 25. Surface preparation costs ($\$/m^2$ ($\$/ft^2$)).

	Cleaning & Painting		Containment		Disposal		Environmental Monitoring		Worker Health		Overhead		Total	
	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
Abrasive Blasting	21.50 - 43 (2 - 4)	26.90 (2.50)	11 - 54 (1 - 5)	21.50 (2.00)	0 - 21.50 (0 - 2)	5.40 (0.50)	0 - 21.50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	54 - 194 (5 - 18)	86 (8)
Wet Abrasive Blasting	32 - 75 (3 - 7)	43.00 (4.00)	11 - 64.50 (1 - 6)	32.25 (3.00)	0 -32 (0 - 3)	21.50 (2.00)	0 - 21.50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	54 - 237 (5 - 22)	129 (12)
Vacuum Blasting	32 - 129 (3 - 12)	86.00 (8.00)	0 - 11 (0 - 1)	0 (0)	0 - 11 (0 - 1)	2.70 (0.25)	0 - 21 50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	43 - 215 (4 - 20)	121 (11)
Water Blasting	32 - 64.50 (3 - 6)	43.00 (4.00)	0 - 75 (0 - 7)	32.25 (3.00)	0 - 11 (0 - 1)	0 (0)	0 - 21.50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	43 - 215 (4 - 20)	107 (10)
Water Blasting with Abrasive Injection	21.50 - 54 (2 - 5)	43.00 (4.00)	11 - 75 (1 - 7)	53.80 (5.00)	0 - 11 (0 - 1)	10.75 (1.00)	0 - 21.50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	43 - 204 (4 - 19)	140 (13)
Power-Tool Cleaning to Bare Metal	43 - 80.75 (4 - 7.50)	64.50 (6.00)	0 - 11 (0 - 1)	10.75 (1.00)	0 - 0 (0 - 0)	0 (0)	0 - 21.50 (0 - 2)	10.75 (1.00)	11- 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	54 - 156 (5 - 15)	97 (9)
Chemical Stripping	21.50 - 43 (2 - 4)	26.90 (2.50)	0 - 21.50 (0 - 2)	10.75 (1.00)	0 - 11 (0 - 1)	5.40 (0.50)	0 - 21.50 (0 - 2)	10.75 (1.00)	11 - 21.50 (1 - 2)	16.00 (1.50)	0 - 21.50 (0 - 2)	5.40 (0.50)	22 - 140 (2 - 13)	75 (7)

Vacuum Blasting

According to information supplied by one of the vacuum-blasting equipment manufacturers, the cost of operating their large units is between \$74 to \$85/h when using steel-grit abrasive, and \$92 to \$134/h when using aluminum oxide abrasive.(62) These estimates include equipment costs (including maintenance), abrasives, consumables, compressor (including fuel), and labor (at \$25/h). Experience has shown that production rates with this size unit vary from 1.4 m^2/h (15 ft^2/h) on structural steel to 5.6m^2/h (60 ft^2/h) on flat steel. Using an average operating cost of \$80/h, the cost of surface preparation would vary from \$14.00 to \$57.00/m^2 (\$1.30 to \$5.30/ft^2). Once materials and painting costs are added, and a difficulty factor applied, the cost estimate of cleaning and painting is \$27.45 to \$123.78/m^2 (\$2.55 to \$11.50/ft^2). As very few bridges have large, flat surfaces, the average cost will be on the high end of the range.

Containment costs are minimal for vacuum blasting as collection of debris is localized at the head. The main environmental concern with vacuum blasting is loss of large particulate matter from improper use of the tool, and a small slug of abrasive or debris during startup/shutdown of the tool. Technically, no containment is needed. Practically, a ground tarp or catch tarp under the work area would be necessary. In cases where the tool is operated improperly, e.g., the head is not kept in contact with the surface, then side tarps will be needed also. For cost-estimate purposes, it must be assumed that the tool will be operated properly. Either no containment or a ground/catch tarp will be used. The cost associated with either of these arrangements is minimal. (Tarps under the work area are not a major investment in either materials or time.)

Disposal costs will depend upon the type of abrasive used. The two most common abrasives are steel and aluminum oxide. Steel abrasive will generate about 2.4 kg/m^2 (0.5 lb/ft^2) of debris. Properly used vacuum blasting will collect all this material for disposal. Though the waste will be classified as non-hazardous, it is known that the debris does not have long-term stability. Therefore, it should be treated with portland cement or disposed as a hazardous waste. The cost, therefore, will be \$1.08 to \$3.55/m^2 (\$0.10 to \$0.33/ft^2). If aluminum oxide were used as the abrasive, about 9.8 kg/m^2 (2 lb/ft^2) of debris will be generated, which has a high probability of being classified as a hazardous waste. The cost of disposal will be \$2.70 to \$5.40/m^2 (\$0.25 to \$0.50/ft^2).

Environmental monitoring, worker health, and overhead/miscellaneous costs will be in the range previously presented. On a practical basis, environmental monitoring costs will be low. When properly used, vacuum blasting is very efficient at collecting the dust and debris generated. A small amount of debris usually escapes when the blasting ends, which can end up on the ground. Air monitoring performed by a manufacturer has indicated only low levels of lead emanating from the equipment, and air monitoring for NAAQS compliance may not be necessary.(50)

Vacuum blasting would be cost-competitive on structures with a high percentage of large, flat surfaces where the larger machines could be used. This results from savings in containment costs and cleanup costs as these functions are built into the equipment. The use of recyclable abrasives, especially steel grit, also assists in minimizing cost. Limitations on proper operation of the equipment, especially on maintaining a proper seal of the blast head to the surface, result in low production rates on small, structural steel members. Vacuum blasting then becomes more expensive or technically unfeasible in these situations.

Water Blasting

The estimate for cleaning and painting was developed based on a production rate that was 50 percent of dry abrasive blasting. The equipment and blasting media costs for dry abrasive blasting and water blasting were judged to be of equal magnitude. In one case, a special water-blasting pump, lance, and water are needed. Dry abrasive blasting requires a compressor, blast pot, and abrasive. At half the production rate, the cost of surface preparation would be $\$21.50/\text{m}^2$ ($\$2.00/\text{ft}^2$). Adding in paint materials and application, and multiplying by the difficulty factor, gives a range of \$31.22 to $\$61.35/\text{m}^2$ (\$2.90 to $\$5.70/\text{ft}^2$).

The cost of containment is dependent upon the type of structure and local regulations. Basic containment will consist of a tarp arrangement with partially sealed or fully sealed joints. For a ground-level structure, this containment would cost about \$2.70 to $\$5.40/\text{m}^2$ (\$0.25 to $\$0.50/\text{ft}^2$). A fully sealed containment would be about \$5.40 to $\$8.10/\text{m}^2$ (\$0.50 to $\$0.75/\text{ft}^2$). A basic containment constructed in the air would be about \$10.76 to \$16.15 m^2 (\$1.00 to $\$1.50/\text{ft}^2$). A basic problem would be containment of the water and paint chips. There is very little experience to give guidance on this cost. For ground-level containment it will be necessary to build a berm or construct a depression so water does not run off. Containments in the air would have to be leakproof and would require a device to channel the water and chips to a container below. Depending on the structure and design of containment, this cost is estimated to be \$5.40 to $\$64.60/\text{m}^2$ (\$0.50 to $\$6.00/\text{ft}^2$).

The amount of solid debris collected would be minimal. A typical structure has about 0.31 to 0.92 kg/m^2 (1 to 3 oz/ft^2) of coating. The paint chips would have a high probability of being a hazardous waste. Using an average of 0.61 kg/m^2 (2 oz/ft^2) of coating, the cost of disposal of the debris would be \$0.11 to $\$0.32/\text{m}^2$ (\$0.01 to $\$0.03/\text{ft}^2$). Collecting the paint chips for disposal must also be considered. This will require a filtering step. The cost of a 5-μm filtering assembly and its operation would increase the disposal cost by a few cents. The cost of disposal becomes extremely high if the water must be disposed. Units capable of removing all paint operate in the range of 69 000 to 345 000 kPa (10,000 to 50,000 lbf/in^2) and use between 3.8 to 53.8 L/min (1 to 14 gal/min). At a production rate of 4.6 $\text{m}^2\text{/h}$ (50 $\text{ft}^2\text{/h}$), the water usage is 0.03 to 0.41 L/m^2 (1.2 to 16.8 gal/ft^2). Using a disposal cost of \$1.92/L (\$400/ gal) for a 208-L (55-gal) drum, the disposal cost becomes \$94.20 to $\$1{,}313/\text{m}^2$ (\$8.75 to $\$122/\text{ft}^2$). On a practical basis, the lead is present in the water as particulate matter and should be capable of being removed by filtering. Therefore, disposal costs will be about \$0.54 to $\$1.08/\text{m}^2$ (\$0.05 to $\$0.10/\text{ft}^2$). The discussion of disposal of water shows that filtering of the water must be addressed prior to any work with the local environmental agencies, as disposal of the water will be extremely expensive.

Environmental monitoring, worker health, and overhead/miscellaneous costs will be in the range previously presented. Water is very effective at minimizing dust and the probability of exceeding NAAQS limits would appear to be low, though this needs to be proven. Soil sampling is highly recommended as there is concern about ground contamination from leakage. However, the cost of soil sampling would be a minimal increase in cost per square foot for most structures.

Insufficient information is available from personal air monitoring to determine if any worker category would be exposed above the PEL. It can only be assumed that since the PEL is so low, it may be possible to exceed this limit even with water blasting. Overhead/miscellaneous would not be impacted by use of water blasting.

It must be remembered that water alone will not remove mill scale and will not impart a surface profile into the steel. As many existing structures that contain lead-based coatings were not initially blast cleaned, comparison of the cost of water blasting to dry abrasive blasting must consider achieving the same surface cleanliness. The cost of surface preparation is \$10.80/m^2 (\$1.00/ft^2). A difficulty factor must be included, giving a range of \$9.70 to \$18.85/m^2 (\$0.90 to \$1.75/ft^2). Containment will be needed to collect the debris. Also, NAAQS for particulates can be exceeded when dry abrasive blasting. The cost for containment from previous discussions is estimated at \$21.50/m^2 (\$2.00/ft^2). The waste generated would be non-hazardous. It is assumed that an expendable abrasive would be used. There would not be a great difference in the amount of abrasive used compared to complete removal by dry abrasive blasting, as most of the energy in dry abrasive blasting is expended on removing the mill scale. Disposal costs, therefore, would be about \$1.40/m^2 (\$0.13/ft^2). Environmental monitoring costs would be for particulates only. There would not be any additional costs for worker health or overhead/miscellaneous, as lead would not be an issue since the coating had been removed. The added costs for the extra surface preparation step would make this method cost-prohibitive under this scenario.

Water Blasting With Abrasive Injection

Using a production rate of 75 percent of dry abrasive blasting, the cost of surface preparation is about \$14.50/m^2 (\$1.35/ft^2). Hence, the cost of cleaning and painting is \$27.00 to \$54.00/m^2 (\$2.50 to \$5.00/ft^2). As production rates are based upon good footing, the average cost is estimated to be on the higher end of the range.

The cost of containment is dependent on the type of structure and local regulations. Basic containment will consist of a tarp arrangement with partially or fully sealed joints. For a ground-level structure where water does not have to be collected, this containment will cost about \$2.70 to \$5.40/m^2 (\$0.25 to \$0.50/ft^2). A fully sealed containment constructed in the air would be about \$10.80 to \$16.15/m^2 (\$1.00 to \$1.50/ft^2).

More complex containment will be needed if it is necessary to collect the water for testing prior to disposal. Water blasting with abrasive injection typically is performed with units that use 19 to 38 L/min (5 to 10 gal/min) of water. One hour of operation by one unit will generate 1135 to 2270 L (300 to 600 gal) of water. The containment must be watertight. Ground-level containments must be built up or depressed in sufficient size to hold the large amounts of water generated in a day. Containments in the air must be sturdy enough to support the weight of the water. The option is to remove the water either by channeling or pumping it to a holding area or tanks.

The containment must also hold the blasting debris generated. As wet blasting with abrasive injection uses about one-quarter the amount of abrasive as dry abrasive blasting, this comes to 12.2 kg/m^2 (2.5 lb/ft^2), or about 91 kg/h/unit (200 lb/h/unit). There is very little field experience with designing and constructing containment where all the debris (liquid and solid) must be collected. The best estimate is \$54.00 to \$75.00/m^2 (\$5.00 to \$7.00/ft^2).

Only expendable abrasives are used for water blasting with abrasive injection. Using the example of 12.2 kg/m^2 (2.5 lb/ft^2), the cost of disposal of non-hazardous and hazardous waste would be \$0.32 to \$1.08/m^2 (\$0.03 to \$0.10/ft^2) and \$3.23 to \$5.92/m^2 (\$0.30 to \$0.55/ft^2), respectively. The cost of collecting the debris must be included in the disposal cost. It is difficult to gather and move damp debris. The cost estimate derived for collection of debris for wet abrasive blasting was \$1.08 to \$5.38/m^2 (\$0.10 to \$0.50/ft^2). The total disposal cost, therefore, would be \$1.40 to \$6.46/m^2 (\$0.13 to \$0.60/ft^2) for non-hazardous waste, and \$4.31 to \$11.30/m^2 (\$0.40 to \$1.05/ft^2) for hazardous waste. As there is a high probability of generating a hazardous waste from a structure coated with lead-based paint, the average cost is estimated to be \$10.76/m^2 (\$1.00/ft^2). Should the water need to be collected and disposed, the cost of disposal of the water must be included. The simplest method would be to filter the water through a 5-μm filter and dispose of it directly. A filtering apparatus and its operation would be only a few cents per square foot. If the water must be disposed as a hazardous waste, the cost would be \$250 to \$500 per drum. At 19 to 38 L/min (5 to 10 gal/min), and a cleaning rate of 7 m^2/h (75 ft^2/h), the disposal cost for the water would be an additional \$194 to \$755/m^2 (\$18 to \$70/ft^2).

Power-Tool Cleaning to Bare Metal

Power-tool cleaning to bare metal is labor-intensive as opposed to equipment-intensive. Basic equipment cost is only a few thousand dollars, expendables are less than \$1/h, and compressor requirements are low. Using a labor charge of \$25/h and a typical crew of four workers and one relief man, the project labor charge would be \$31.25/tool-hour. Therefore, once equipment charges, compressor, fuel, etc., are added in, a project labor rate of \$35/tool-hour is reasonable. Obviously, if local labor rates are higher, the average hourly cost would be higher. Available information indicates that production rates vary from about \$0.09 to \$1.40 m^2/h (10 to 15 ft^2/h). This gives a cost for surface preparation in the range of \$15.07 to \$37.67/m^2 (\$1.40 to \$3.50/ft^2). The test performed for this research project indicated cleaning rates on bridges were at the low end of the production range. Therefore, a basic surface preparation cost of \$32.30/m^2 (\$3.00/ft^2) would be most appropriate. Adding in paint material costs and multiplying by the difficulty factor gives an estimate of cleaning and painting costs in the range of \$43.00 to \$80.70/m^2 (\$4.00 to \$7.50/ft^2).

Containment costs are based on the use of loose attached drapes with no ventilation system. This was previously estimated to cost about \$2.70 to \$5.40/m^2 (\$0.25 to \$0.50/ft^2), increasing to \$5.70 to \$8.07/m^2 (\$0.50 to \$0.75/ft^2) if full seals are required, and \$10.80 to \$16.15 (\$1.00 to \$1.50/ft^2) if constructed in the air. If vacuum power tools were used, it would still be recommended that ground tarps or catch tarps be used as material can escape due to improper use of the tool or working in tight areas. The cost of ground/catch tarps is minimal.

Waste-disposal costs would be low as the waste consists only of paint chips, rust, and mill scale. The waste from removing lead-based coating systems has a high probability of being classified as a hazardous waste. With 305 to 1220 g/m^2 (1 to 4 oz/ft^2) of coating, and disposal costs of $276 to $496/t ($250 to $450/ton), the estimated cost of disposal would be in the range of $0.11 to $0.65/m^2 ($0.01 to $0.06/ft^2).

Environmental monitoring, worker health, and overhead/miscellaneous costs are in the ranges previously presented. The probability of exceeding NAAQS outside the work area is low according to an evaluation already cited, and even lower when vacuum power tools are used. Workers can be exposed above the PEL when removing lead paints—even when using vacuum-shrouded power tools on bridges.

Chemical Stripping

Surface preparation costs are based on being able to remove all the coating with one application of the stripper. Application of the stripper and removal by hand methods can be performed at a rate of 4.6 to 9.3 m^2/h (50 to 100 ft^2/h). Coverage rates vary, with typical rates being 0.37 to 0.74 m^2/L (15 to 30 ft^2/gal). The cost of the stripper is $2.64 to $4.00/L ($10 to $15/gal). Using a labor rate of $25/h, the cost for coating removal would be in the range of $5.38 to $16.15/m^2 ($0.50 to $1.50/ft^2). Spray application is possible, which will increase the area that can be stripped in a day, but more labor would be necessary for removal. Equipment costs for spray application, disposables, etc., must be included. For estimating purposes, an average cost for surface preparation, therefore, is $10.76/m^2 ($1.00/ft^2). This is the same estimated cost as abrasive blasting, giving an estimated cost for cleaning and painting in the range of $21.53 to $43.06/m^2 ($2.00 to 4.00/ft^2).

Containment costs will depend upon the type of structure. It must be appreciated that the stripper and debris has a sludge-like consistency. Any water used for cleaning must also be controlled by the containment. The sludge is picked up manually with shovels. For low structures such as grade separations, a layer of plastic or a tarp on the ground would not be sufficient. A more substantial ground cover would be needed. For example, the literature describes one job where containment around a ground storage tank consisted of 760-μm- (30-mil-) thick sheets of rubber that were glued and taped together, extending approximately 6.1 m (20 ft) out from the tank, with cinder blocks placed under the outer edge to form a berm around the tank.(48) Containments in the air would have to be constructed with solid floors, such as plywood, and sealed in some manner so liquid would not drip through. Side tarps may also be needed to protect the material from drying out in the sun. Containment costs are estimated at $5.40 to $21.50/m^2 ($0.50 to $2.00/ft^2).

Disposal costs will depend upon the usage rates of the stripper. As strippers have high solids content, and loss of solvent is partially counterbalanced by the paint removed, each gallon of stripper generates close to 3.8 L (1 gal) of waste. Practically, the recovery rate is in the range of 1.9 to 3.8 L (0.5 to 1.0 gal) of waste per 3.8 L (1 gal) of stripper. The waste from removing lead-based paints has a high probability of being classified as a hazardous waste. Using 0.61 m^2/L (25 ft^2/gal) as the usage rate, and a disposal cost of $400 per drum, the range of disposal costs is $1.60 to $3.20/m^2 ($0.15 to $0.30/ft^2). Note that the stripper can be removed, or the surface washed, with high-pressure/low-volume spray. These units generate only a few tenths of a gallon of water per minute, which can be incorporated with the stripper debris. Therefore, no extra costs for separation and disposal of water is included in the cost estimate.

Chemical stripping removes only the paint. Removing mill scale and rust to achieve a Near-White Metal (SSPC-SP10) finish will require a second blasting step. The cost for the second blasting step was previously determined in the discussion of the cost of water blasting.

SECTION IX: SUMMARY AND CONCLUSIONS

The objectives of this study were to evaluate a number of issues related to lead-paint removal, and to establish guidelines for highway agencies. The major findings and conclusions are presented below.

GENERAL

1. A significant number of highway agencies do not fully understand the regulations or the liability involved with lead removal and the consequences of failing to comply.

2. Special contract provisions must be written in detail that ensure that work performed will be in compliance with current environmental and worker safety regulations. The simple statement that "the contractor shall be in conformance with all Federal, State, and local regulations" is not sufficient. In addition, it is in the best interest of the highway agency to ensure that all contractors are bidding projects with the same level of compliance. Since there are such wide variations in the level of understanding of the regulations by contractors, the only way to ensure that all contractors will bid projects at similar levels of compliance is to specify the minimal requirements and to hold a mandatory pre-bid meeting. If these are not done, and States must use the low-bid process, it will ensure that the contractor with the worst understanding (or most willing to take a chance on lack of enforcement) will be the lowest bidder. Project delays and shutdowns, claims for extras, and third-party lawsuits brought against the State by employees of painting contractors and/or the public have occurred. These problems can be avoided (or at least minimized) with adequate special provisions and a mandatory pre-bid meeting.

3. Highway agencies must reevaluate maintenance painting programs. Due to the high cost and liability, it is no longer an option to simply "blast and paint." Open abrasive blasting is no longer permissible. Well thought out maintenance strategies that minimize cost per service year over the life of the structure must be developed. This may involve a combination of methods, including spot painting, zone painting, beam replacement, and total removal of the paint. Computer programs and standard failure assessment inspection criteria should be developed so that a cost-effective maintenance painting program can be developed using life-cycle costs. Work should also be performed to determine the effective service life of coatings used over existing coatings. Without accurate service-life predictions of various coatings over existing paints (something lacking in the highway industry), all manner of products will be used without performance documentation and with service-life projections of reduced accuracy and value.

4. Containment guidelines, requirements, and specifications have greatly improved over the course of the research project. Work was performed to increase the understanding of the effects of the limits contained in the guidelines and specification. More needs to be done. The effect of current recommendations and requirements need to be studied. In some cases, current requirements may be too stringent; in other cases, requirements may be too lax. Careful analyses of future projects need to be performed. This should be done on the

Federal level in a cooperative effort with the transportation, environmental, and OSHA-NIOSH agencies.

LEAD TESTING

1. Title X regulations will require the use of certified laboratories—probably by 1995. The use of certified laboratories should be specified.

2. Highway agencies should specify the test methods to be used to determine total lead in paints. There are significant differences in the results obtained via the various methods. ASTM Method D3335 should be specified. EPA Method 3050 and NIOSH Method 7082 were unacceptable for the determination of total lead in bridge paint. The proposed EPA Method PB92-114172 will be acceptable if the procedure is adopted in its current form.

3. The requirement for duplicate samples in ASTM Method D3335 is not necessary for determining total amount of lead in highway paints. Lead values are usually so high or so low that the duplicate has little value. Proper quality control procedures ensuring accurate analysis should be required, however. This is more valuable than requiring samples in duplicate.

4. Testing for lead in the presence of steel is fraught with problems. Current methods have very poor lead recoveries with some steel grits. Procedures must be developed for determining total lead in the presence of steel grit; otherwise efforts to accurately determine the cleanliness of recycled steel abrasives will continuously be an unresolvable problem.

5. Specifying lead concentrations in recycled abrasives has merit in reducing the amount of lead reintroduced into the work area. However, the level of lead specified must recognize the capability of analytical procedures, the natural existence of lead in steel abrasives, and that 100 percent removal of lead-containing particles by recycling equipment is not achievable. The lowest level that should be specified is 1,000 ppm lead, and even this may be too stringent.

6. In the absence of information or data on the total lead content in the paint, it should be assumed that the bridge is coated with paints containing high levels of lead. Regulations pertaining to lead apply whenever the coating will be disturbed. This includes activities besides painting, such as welding, cutting, or heat-straightening operations. State maintenance personnel must be properly protected, debris collected and properly disposed, and adequate environmental protection used when performing many types of activities on lead-painted bridges.

REGULATIONS

1. Regulations that impact bridge painting are changing at a rapid pace. In most cases, they are becoming more stringent. State highway agencies need to stay abreast of these regulations and provide commentary during the regulatory development process.

2. Title X will have a significant impact on bridge painting. The cost of the extensive training requirements will be passed on to the owner. When certifications becomes mandatory, a shortage of workers may occur. Though still at least 2 years away, highway agencies need to encourage contractors to have their workers certified, once the training requirements are publicized.

3. Highway agencies need to require and ensure compliance with regulations. Lack of compliance with the regulations by the contractor can result in job shut-down and potential legal action against the highway agency.

4. There is a high probability of exceeding regulatory limits for hazardous waste, air/water/soil quality, and worker exposure when removing lead-based paints from bridges. This is due in part to the high concentration of lead in the paint film. Further research and evaluations are needed to determine the probability of exceeding regulatory limits for lower levels of lead in the paint film.

5. Highway agencies should monitor or require independent air monitoring on projects for lead emissions. The awareness level of the general public regarding lead continues to increase. Monitoring will show the public that the highway agency is pro-active towards the issue, and will have the data to substantiate the level of emissions. Monitoring is the only way to ensure that work is being performed in compliance with the regulations. In addition, there is insufficient data relating air quality to the many variables associated with surface preparation methods and containment. A data bank of information may allow reasonable confidence that costly air monitoring would not be needed for certain combinations.

6. Monitoring for air emissions must be done in accordance with EPA procedures. Other air-sampling devices do not correlate with TSP and PM_{10} monitors. Further evaluations of visible-emission methods are recommended. Visual emissions have the advantage of immediate feedback; however, a correlation between a reasonable level of visible emissions that ensures compliance with Clean Air Act (CAA) limits must be developed.

7. Pre-job soil samples should be taken. The lead levels in the soil in the highway right of way and immediate surrounding area can be very high, exceeding proposed cleanup levels. Soil samples taken after a painting project can wrongly assign lead activities. Pre-job soil samples will document the background level of lead in the soil at that site.

CONTAINMENT

1. SSPC Containment Guide 6I (CON) is an effective document for specifying containment. Further definition of some of the requirements in the specification would increase the probability of a successful project, especially when abrasive blasting is specified.

2. Only air-impermeable materials should be allowed for constructing containments when abrasive blasting is performed. Uncoated woven materials do not appear to be impermeable to lead. Coated, woven materials, while initially impermeable to lead,

deteriorate with time. Durability requirements for the containment material should be specified. A minimum of 1.5 m (5 ft) between the containment and the steel should be required when flexible materials are used to construct containment to avoid perforating the material.

3. Properly designed and sized air inputs are essential for airflow through containment. High-speed, low-volume fans were found to be most effective. A baffle was also found to be effective for air movement, but improper design allows dust to escape into the environment when the blast nozzle is near or pointed towards the baffle. Louvers or filters would reduce the amount of dust that escapes.

4. Fully sealed joints do not allow dust to escape into the environment. Bull seams are not effective.

5. Negative pressure of 0.75 mm (0.03 in) water column inside containment was effective at keeping dust from escaping.

6. Many factors contribute to lead exposure in the worker, including the high-speed air exiting the blast. No difference in worker exposure was found by increasing the ventilation airflow above the current velocity of 31 m/min (100 ft/min) in a cross-draft direction recommended for visibility purposes. Lower velocities should be evaluated to determine if lower airflows are adequate.

7. Adequate airflow is needed to clear containment of dust when blasting ceases. Adequate airflow includes velocity and distribution. Velocity is best determined by measuring the air volume drawn through the exhaust ducts and dividing by the cross-sectional area of the containment. Air distribution can best be determined with smoke bombs. Measuring air velocity inside containment with an anemometer was found to be inaccurate. Properly designed and functioning input and exhaust plenums can provide uniform airflow through containment.

8. Standards for limiting and measuring the lead emissions from dust collectors, vacuum recovery, and air transfer systems must be developed. These units have a high potential for emitting enough lead to result in a CERCLA violation. Consideration should be given to requiring automatic shutdown devices if a filter collapses. Instruments to measure on-line sampling should be developed (similar to respiratory fit test equipment, for example).

9. Further research efforts are needed on containment/ventilation blasting to better define the critical parameters.

WORKER HEALTH

1. Following the requirements of the OSHA Lead in Construction Industry Standard appears to be effective at reducing the probability of workers becoming poisoned by lead.

2. On a structure containing 50 percent lead in the dry film, the best engineering control from a ventilation system can be expected to reduce blaster's exposure to lead to somewhere in the range of 5000 to 15 000 $\mu g/m^3$.

3. A State or regional program similar to Connecticut's CRISP program can be effective in medical monitoring of workers, especially for a mobile work force such as bridge painters whose employment is limited by the project.

4. Type CE blast helmets were found to have a minimum protection factor of 500. More exposure measurements made inside and outside of type CE blast helmets are needed to confirm the actual protection factor that can be achieved under field conditions.

WASTE

1. Highway agencies will be classified as the generator and will be responsible for lead-containing waste in memorium. Though aspects of handling surface preparation debris will be delegated to the contractor, the highway agency must be especially concerned that the debris is properly disposed. Contracting for waste disposal with a firm that specializes in waste handling separate from the painting contractor can provide greater assurance of proper disposal.

2. Waste streams generated by the use of steel additives with an expendable do not have long-term stability, though they initially may be classified as a non-hazardous waste by Toxicity Characteristics Leaching Procedure (TCLP) testing.

3. Portland cement mixtures have the highest probability of long-term stability of hazardous waste.

4. The method that provides the highest protection against potential future liability appears to be blast cleaning with recyclable steel abrasives and having the waste taken to a secondary lead smelter. The relatively high lead and iron content in the debris appears to make the debris an attractive raw material for the smelters. If steel abrasive waste is disposed, highway agencies should require disposal at a hazardous waste landfill, regardless of the results of hazardous waste testing.

SURFACE PREPARATION

1. Dry abrasive blasting appears to be the most cost-effective method for total coating removal and surface preparation. Other surface preparation methods do have advantages, such as limiting environmental emissions or worker exposure.

2. The use of recyclable steel abrasives minimizes the amount of waste generated that, if hazardous, will be costly to dispose. Recyclable steel abrasives reduce the amount of waste by 90 percent or more compared to expendable abrasives. The cost savings for disposal appears to be equal or more than the added equipment costs for recycling

equipment. Highway agencies should consider specifying high-pressure 870-kPa (125-lbf/in^2) blasting to maximize productivity and minimize cost.

3. Every surface preparation method monitored resulted in worker exposures above the PEL, even vacuum and low-dusting methods. One contributing factor was the high level of lead in the paint film, which was typical of paints on highway bridges.

4. The cost of the actual surface preparation and painting is currently less than half the project cost. The cost of containment and worker protection would make the use of Brush-Off (SSPC-SP7) blast cleaning economically unattractive. As the cost of surface preparation and coating materials are now a much smaller percentage of the total project cost, life-cycle costs could be minimized by blast cleaning to a high level of cleanliness, such as Near-White (SSPC-SP10), and applying a high-performance coating system.

APPENDIX A. LEAD TESTING

The total lead content of a paint and the leachability of the debris are critical tests. Decisions on painting projects require knowledge of the total lead content in the paint. Leachability is determined by the Toxicity Characteristics Leaching Procedure (TCLP) method and is critical as it characterizes the toxicity of the waste for disposal decisions. The heavy metal content is not only a function of sampling protocol, but can vary widely by the analytical procedure used by the laboratory. Of particular concern is the effect of iron on lead and chromium results. Unfortunately, the test procedures that have been developed were based on matrices different than normally encountered with paints, or for paints used in the housing industry. In performing this research study it became obvious that the lead in typical bridge paints needed better definition. To that end, a series of tests were initiated to evaluate procedures used to determine the total lead content in paint and abrasive mixtures (both disposable and recyclable). In addition, the relationship between total lead and leachable lead, various leaching procedures, and the effects of two analytical techniques were compared. Results of these evaluations are reported in this appendix.

TOTAL LEAD AND CHROMIUM IN PAINT CHIPS

Four test methods were evaluated. They were: ASTM D3335, NIOSH 7082, EPA 3050, and ASTM D3718. These methods are the ones most commonly used by testing laboratories. Each of these methods was designed for a specific purpose. They are routinely used to determine total lead content in paints, even though none of them was designed to measure lead in the concentration typically found in the bridge paints. ASTM D3335, according to the scope of the procedure, is appropriate for a maximum lead content of 5 percent. Lead in bridge paint is usually much higher than what is appropriate for this procedure. NIOSH 7082 is a procedure for measuring total lead content of personal air-monitor filters. This procedure was designed to test samples with low levels of lead and chromium present in very small particle sizes. Both of these criteria are not typical of bridge paints. EPA Method 3050 was designed for low levels of lead and chromium in soils, sediments, and sludges, a vastly different matrix and concentration range than that found with typical bridge paints. ASTM D3718 is designed for low levels of chromium. It is suitable for paints in the highway industry, but it is an expensive procedure when compared to the other tests. For convenience, the actual analytical procedures are outlined in appendix H.

Near the end of the research project a copy of the proposed EPA procedure, PB92-114172, was obtained from the National Institute of Standards and Technology (NIST). This procedure may become the standard method under Title X. This procedure is similar to the NIOSH 7082 method, but it is said to be more specific for lead in paints. It not only contains excellent, detailed procedures, but also quality control guidelines. A review of the method indicated that these guidelines appeared to be unachievable when used to test paints commonly found in the industrial sector and, in particular, on highway bridges. This method requires an 8 or 9 percent relative difference using only a 0.1-g sample size. This may not be achievable with a typical sample of paint from a bridge. Therefore, it was decided to run an evaluation on the method. Due to time constraints, the method was evaluated only for total lead and chromium in paints.

Since this was a research project and numerous replicates were performed, the quality control procedures were not followed as rigorously as required in standard EPA procedures. Quality control consisted of the following:

- A calibration blank was analyzed every 10 samples.
- Check Standards were analyzed after the calibration and after every 10 samples.

All tests were run on an Inductively Coupled Plasma Emission Spectrophotometer (ICP) in accordance with EPA Method 6010.

Significant variability exists in analytical results obtained from measuring heavy metal content in a sample. Many laboratories are using percent relative standard deviation to document this variability. Percent relative standard deviation (%RSD) is the standard deviation divided by the mean of all values and multiplied by 100. It is common to have relative standard deviations in the range of 10 percent. Values up to 20 percent are usually acceptable.

Three different paints were tested for lead and chromium, each with 10 replicates. The sources of the paints were:

NIST Paint 1579a

This material was purchased from the National Institute of Standards and Technology. It originally was obtained from interior surfaces of a dwelling in the Philadelphia area using heat techniques to remove the paint. It was ground until 99.31 percent by weight passed through a 45-μm (no. 325) sieve. It has a certified lead concentration of 11.995 ± 0.031 weight percent.

Milled Bridge Paint

Paint was removed from a typical highway structure in Michigan with vacuum-shrouded power tools. The paint chips that were collected had a particle size that was much too large to resemble abrasive blasted paint. Since it was not possible to separate lead paint from abrasive and lead paint mixtures, and because small particles were necessary, the paint chips were milled to a smaller size. This milling procedure consisted of making a slurry using 800 g of paint and 500 g of distilled water in a blender. The slurry was blended until there was a 20 °C increase in the temperature of the slurry. The mixture was then dried in a 100 °C oven and sifted through a 425 μm (no. 40) sieve. This resulted in a paint dust that appeared much similar to what is typically found in spent abrasive; however, particle size studies to determine exactly how close in size it was were not performed. It should also be noted that the particle size was much smaller than the typical paint sample that is supplied to laboratories for total lead or chromium analysis.

Ashed Bridge Paint

Paint was removed from a typical highway structure in Michigan with vacuum-shrouded power tools. The paint was ashed at 500 °C in a muffle furnace for 45 min, then it was ground using a mortar and pestle. This resulted in a paint dust with a very small particle size, similar to the NIST 1579a. Tests were not performed to determine actual particle size.

TEST RESULTS

Table 26. Lead and chromium content of paints analyzed by ASTM Method D3335.

Replicate	NIST 1579a		Milled Bridge Paint		Ashed Bridge Paint	
	% Pb	% Cr	% Pb	% Cr	% Pb	% Cr
1	12.9	0.02	47.1	0.23	59.0	0.36
2	11.6	0.02	39.9	0.46	63.6	0.49
3	11.2	0.02	46.0	0.23	66.7	0.42
4	10.5	0.02	46.8	0.22	62.4	0.38
5	11.6	0.02	47.0	0.23	62.2	0.45
6	11.4	0.02	46.7	0.23	62.1	0.36
7	14.3	0.02	44.6	0.25	60.5	0.58
8	12.8	0.02	44.0	0.26	62.3	0.45
9	11.3	0.02	44.0	0.24	60.3	0.40
10	12.4	0.02	46.5	0.25	65.4	0.61
Average	12.0	0.02	45.3	0.26	62.4	0.45
%RSD	9.3	0[1]	5.0	27.3	3.7	19.3

[1] Apparently no chromium in the sample.

Table 27. Lead and chromium content in paints analyzed by NIOSH Method 7082.

Replicate	NIST 1579a		Milled Bridge Paint		Ashed Bridge Paint	
	% Pb	% Cr	% Pb	% Cr	% Pb	% Cr
1	11.6	0.02	35.8	0.23	59.8	0.29
2	9.7	0.02	33.7	0.23	46.4	0.27
3	10.5	0.02	43.2	0.24	51.2	0.24
4	8.9	0.02	42.0	0.24	46.3	0.23
5	10.4	0.02	39.5	0.24	54.9	0.28
6	9.8	0.02	31.7	0.25	50.0	0.24
7	8.7	0.02	33.2	0.25	56.0	0.27
8	8.8	0.02	41.0	0.24	54.3	0.28
9	8.0	0.02	35.3	0.25	53.0	0.25
10		0.02	40.7	0.25	57.5	0.28
Average	9.6	0.02	37.6	0.24	52.9	0.27
%RSD	11.7	0[1]	11.0	2.90	8.5	7.8

[1] Apparently no chromium in the sample.

Table 28. Lead and chromium content in paints analyzed by EPA Method 3050.

Replicate	NIST 1579a		Milled Bridge Paint		Ashed Bridge Paint	
	% Pb	% Cr	% Pb	% Cr	% Pb	% Cr
1	8.2	0.02	15.3	0.25	18.7	0.30
2	7.9	0.02	13.8	0.29	19.2	0.31
3	10.1	0.02	13.0	0.22	19.3	0.32
4	8.2	0.02	18.8	0.25	12.9	0.24
5	10.1	0.02	14.7	0.23	13.9	0.24
6	8.3	0.02	10.5	0.23	17.7	0.33
7	8.9	0.02	13.3	0.24	14.6	0.29
8	9.3	0.02	9.1	0.25	18.6	0.26
9	8.5	0.02	12.3	0.20	19.7	0.35
10	8.4	0.02	11.5	0.24	18.2	0.29
Average	8.8	0.02	13.2	0.24	17.2	0.29
%RSD	8.8	0[1]	20.6	8.10	14.2	13.4

[1] Apparently no chromium in the sample.

Table 29. Lead and chromium content of paints analyzed by ASTM Method D3718.

Replicate	NIST 1579a		Milled Bridge Paint		Ashed Bridge Paint	
	% Pb	% Cr[2]	% Pb	% Cr[1]	% Pb	% Cr
1	0.2	0.01		0.21	0.83	0.58
2	0.3	0.01		0.18	0.84	0.75
3	0.3	0.01		0.14	0.82	0.51
4				0.14	0.83	0.42
5					0.84	0.50
6					0.79	0.54
7					0.75	0.57
8					0.82	0.53
9					1.15	0.56
10					2.55	0.62
Average					0.99	0.56
%RSD					46.0	15.7

[1] Initial test results indicated poor analytical recovery. Testing ceased after a few samples.

[2] Apparently no chromium in the sample.

Table 30. Lead and chromium content of paints analyzed by EPA-proposed Method PB92-114172.

Replicate	NIST 1579a[1]		Milled Bridge Paint[1]		Ashed Bridge Paint	
	% Pb	% Cr	% Pb	% Cr	% Pb	% Cr
1	9.0	0.02	48.1	0.25	56.8	0.23
2	9.1	0.02	47.5	0.23	63.2	0.23
3	10.0	0.02	50.1	0.22	58.9	0.22
4	11.0	0.02	47.0	0.23	63.6	0.22
5	8.8	0.02	49.4	0.23	61.4	0.22
6	10.4	0.02	50.4	0.24	61.5	0.23
7	11.0	0.02	48.7	0.24	60.1	0.22
8	8.6	0.02	49.0	0.23	61.4	0.22
9	10.2	0.02	50.5	0.25	62.1	0.22
10	9.8	0.02	46.2	0.24		
Average	9.8	0.02	48.7	0.24	61.0	0.22
%RSD	9	0.00[1]	3.0	4.10	3.5	2.2

[1] Apparently no chromium in the sample.

DISCUSSION OF TOTAL LEAD AND CHROMIUM TESTING

The results clearly indicated that certain of these procedures did not give acceptable results. EPA Method 3050 was found to be unacceptable for bridge paints. The average lead content was less than half the other methods. ASTM Method 3718 was also found to be unacceptable for measuring lead.

It appears that the highest lead concentrations were achieved with ASTM Method D3335 even though it was not designed for lead values in the range typically found on bridges. NIOSH Method 7082 gave high recoveries, though not as high as ASTM Method D3335. The data indicated that ASTM Method D3335 was the most appropriate method for determining lead content in typical bridge paints. It was the only method that accurately measured the lead content in the NIST standard paint sample. It appears that bridge-paint samples analyzed by any of the other methods evaluated will give a low lead content.

No standard paint sample of know chromium content was available, so evaluation of the analytical methods was more difficult. NIOSH Method 7082 does not appear appropriate for chromium in paint. Though the %RSD for chromium by this method showed precision of the procedure, the average chromium content in the two paints were the same. The difference between the two bridge-paint samples was that one was milled and the other was ashed at 500 °C. Ashing at this temperature would burn off the binder. Therefore, the chromium content in the ashed sample would be expected to be higher. EPA Method 3050 also gave similar chromium contents for the two bridge paints and, therefore, this method was also suspect. ASTM Method D3335 had a high %RSD for the milled paint, the form that most closely represented a typical paint chip sent to a laboratory. Even the results obtained using ASTM Method D3718 were questioned, as the chromium content of the milled paint appeared low compared to the ashed paint based on typical binder content in paint.

Determining the presence of chromium in bridge paints and analysis of chromium are important. Chromium is regulated under RCRA, and OSHA recently announced a notice of proposed regulation for worker exposure. The data obtained during this research indicated that further evaluation is needed of methods for analyzing chromium content.

DISCUSSION OF PROPOSED METHOD

The proposed method, EPA PB92-114172, appeared to be an acceptable technique. At high lead concentrations, the relative difference requirements were achieved. As these were the first tests performed with this method, the probability is that the recoveries and variability will be reduced. In a discussion with NIST personnel, it was indicated that 90 to 95 percent recoveries are more typical. The procedure required that there be less than 9 percent relative difference in the values. This was achieved on the bridge paints; it was not achieved on the NIST paint. Only more experience with the method and more samples will ultimately determine if the quality control requirement of the method can be met with typical highway paints.

TOTAL LEAD AND CHROMIUM IN ABRASIVE

DISPOSABLE ABRASIVE

All procedures, quality control, and paints were the same as in the previous tests. The difference in this test was that the paints were added to a mineral sand abrasive in known concentrations. The mineral sand was a staurolite abrasive.

Based on the results obtained using ASTM Method D3335 in the previous section and 20 replicates, the lead concentration was determined to be 50.1 percent in the batch of ashed bridge paint used to spike the abrasive samples. Samples of abrasive were spiked to 1000 mg/kg, 200 mg/kg, 50 mg/kg, and 0 mg/kg of lead. Chromium spikes were not performed, though the chromium content was measured and reported.

Samples were made by adding the appropriate amount of paint dust—approximately 2 g of ashed bridge paint to 998 g of abrasive and 5 g of NIST 1579a to 495 g of abrasive, to yield a 1000-mg/kg mixture. Samples were mixed on a Kitchen Aid® mixer at the lowest speed for 30 min. 100 g of this mixture were diluted with 400 g of abrasive and mixed as above to obtain the 200-mg/kg samples. 100 g of the 200-mg/kg sample were mixed with 300 g as above to obtain the 50-mg/kg samples. Results of these analyses are reported in tables 31 through 37.

RECYCLABLE STEEL ABRASIVE

TOTAL LEAD AND CHROMIUM IN A RECYCLABLE ABRASIVE

All procedures, quality control, and paints were the same as in the section above. The difference in this test is that the paint dusts were added to two different types of ferrous metallic abrasives (steel grits). Type 1 was a new G-40 grit and type 2 was a ferrous metallic abrasive that was a combination of angular and round particles that were the same size as type 1. Results of these analyses are reported in tables 38 through 51.

DISCUSSION OF RESULTS

The results of the analyses performed on paint in a mineral sand abrasive indicated that the three analytical methods evaluated gave identical results. It appears that these standard methods are accurate at low lead concentrations, which was not true at high lead concentrations.

The data from measuring total lead in an iron matrix indicated fair reproducibility within each method, but high variability among the methods. This is important to highway departments that are specifying that the grit must be cleaned to a specific value. Analytical procedures must be capable of measuring the specified level of lead with some accuracy. The two matrices that were tested were significantly different. The lowest level of lead that could be measured accurately for type 1 metallic abrasive was 125 mg/kg using ASTM Method D 3335 or EPA Method 3050 with the lead concentration measured with an ICP. There was either too much lead in the steel or too much interference from the iron to obtain reliable results below this value on the ICP. It appears that specific procedures must be developed for lead in high iron matrices. Until procedures are better defined, there will always be controversy over the results of lead in steel grit analysis.

Table 31. Lead and chromium content in abrasive spiked to 1000 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	1025	128	825	104	714	147
2	697	140	898	154	961	159
3	1021	157	784	162	912	153
4	938	171	753	158	801	136
5	894	130	779	110	982	135
6	932	130	728	127	993	181
7	848	105	813	113	947	192
8	663	169	744	123	922	167
9	986	102	770	137	1172	120
10	927	108	1025	128	905	123
Average	893	134	812	132	931	151
%RSD	14.0	18.9	11.0	15.7	12.9	15.8

Table 32. Lead and chromium content in abrasive spiked to 200 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	194	112	124	82	167	107
2	260	163	125	142	107	127
3	204	141	152	152	191	122
4	225	119	158	83	147	131
5	168	185	136	112	194	101
6	211	157	162	127	140	115
7	88	42	193	145	149	96
8	273	152	177	123	197	155
9	219	162	198	107	165	99
10			129	144	165	74
Average	205	137	155	122	162	113
%RSD	26.5	30.8	17.6	20.8	17.3	20.0

Table 33. Lead and chromium content in abrasive spiked to 50 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	63	91	45	118	20	162
2	51	131	58	127	107	146
3	59	262	49	126	56	88
4	55	231	35	156	43	203
5	49	280	43	109	22	193
6	49	166	45	141	33	150
7	77	222	30	151	43	167
8	61	230	48	183	41	182
9	52	199	51	115	75	239
10	56	159	39	137	50	178
Average	57	197	44	136	49	171
%RSD	14.9	30	18.3	16.5	52.9	23.4

Table 34. Lead and chromium content in abrasive spiked to 0 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	11	124	8	106	10.	169
2	7	90	9	115	9	177
3	7	132	7	106	10	144
4	8	122	8	131	8	105
5	7	145	7	67	5	89
6	11	118	7	79	9	120
7	8	156	6	98	8	134
8	BDL[1]	119	8	78	8	136
9	10	139		73	7	74
10		86		120	10.	147
Average	8	123	7	97	8	130
%RSD		18	12.2	22.6	19.5	25.5

Below detectable limits.

Table 35. Lead content in abrasive spiked to 1000 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	1190	963	821
2	594	977	963
3	1108	1007	935
4	1105	982	905
5	1080	1108	717
6	988	1030	884
7	1001	1073	892
8	986	1042	925
9	967	1041	886
10	959	1076	870
Average	998	1029	880
%RSD	16.1	4.6	7.8

Table 36. Lead content in abrasive spiked to 200 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	199	194	191
2	201	178	178
3	202	180	165
4	190	175	186
5	164	185	212
6	187	195	188
7	197	190	178
8	177	173	175
9	150	168	180
10	198	184	170
Average	188	182	182
%RSD	9.4	5.0	7.2

Table 37. Lead content in abrasive spiked to 50 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	61	41	45
2	49	45	50
3	57	43	52
4	51	43	49
5	57	43	56
6	44	45	48
7	45	38	49
8	55	56	57
9	59	43	47
10	66	38	47
Average	54	44	50
%RSD	13.0	11.6	7.8

Table 38. Lead and chromium content in type 1 grit spiked to 1000 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	354	2472	282	1549	653	2418
2	722	2549	273	1271	317	2343
3	460	2623	299	1528	307	2454
4	359	2821	285	1421	241	1943
5	367	2562	286	1287	258	2030
6	386	2909	312	1345	426	2163
7	332	2569	337	1289	318	1766
8	389	2440	391	1376	324	1867
9	420	2684	318	1286	1053	2079
10	439	2740	419	1331	301	2547
Average	423	2637	320	1368	420	2161
%RSD	26.6	5.72	15.3	7.4	59.9	12.4

Table 39. Lead and chromium content in type 1 grit spiked to 200 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	161	2515	131	1636	172	2681
2	150	2518	132	1591	189	3046
3	162	2516	160	1592	185	2824
4	155	2620	132	1591	175	2951
5	156	2582	160	1592	194	3131
6	197	2667	124	1594	180	2953
7	121	2658	121	1467	178	2979
8	174	2489	118	1362	191	2914
9	237	2728	149	1358	178	2976
10	160	2513	126	1499	167	2765
Average	172	2581	135	1528	181	2922
%RSD	15.3	3.24	11.5	6.6	4.8	4.6

Table 40. Lead and chromium content in type 1 grit spiked to 50 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	122	2605	70	1322	116	2765
2	118	2629	77	1490	121	2024
3	114	2534	64	1265	122	2220
4	109	2737	64	1284	124	2198
5	125	2600	72	1380	126	2364
6	124	2603	71	1448	122	2198
7	115	2478	65	1209	111	2391
8	113	2409	70	1407	123	1595
9	112	2524	66	1215	125	2255
10	106	2369	58	1129	118	2358
Average	116	2549	68	1315	116	2237
%RSD	5.5	4.3	7.9	8.8	5.5	13.3

Table 41. Lead and chromium content in type 1 grit spiked to 0 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	142	2320	63	989	125	2048
2	131	2147	71	1133	122	1927
3	132	2285	72	1171	123	2167
4	149	2365	74	1227	129	2177
5	118	2052	71	1175	130	2123
6	149	2524	73	1245	131	2009
7	132	2274	68	1123	130	1848
8	133	2446	71	1210	126	1829
9	134	2404	69	1113	123	2072
10	105	1171	73	1201	127	
Average	133	2199	71	1158	126	2022
%RSD	10.1	17.6	4.5	6.4	2.6	6.4

Table 42. Lead content in type 1 grit spiked to 1000 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	1063	789	874
2	961	894	861
3	1008	891	800
4	1049	831	870
5	923	837	841
6	965	801	847
7	1005	816	860
8	984	872	890
9	1121	811	84
10	950	829	865
Average	1003	837	855
%RSD	6.0	4.4	2.8

Table 43. Lead content in type 1 grit spiked to 200 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	297	178	220
2	302	231	231
3	278	234	225
4	306	217	209
5	296	227	216
6	304	241	222
7	293	203	228
8	254	239	248
9	310	217	208
10	303	217	222
Average	294	220	222
%RSD	5.7	8.6	4.5

Table 44. Lead content in type 1 grit spiked to 50 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	120	89	127
2	117	95	127
3	127	101	135
4	144	101	140
5	130	102	132
6	140	91	129
7	131	90	125
8	150	91	135
9	142	92	140
10	136	103	135
Average	134	96	133
%RSD	8.0	5.9	4.4

Table 45. Lead and chromium content in type 2 grit spiked to 1000 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	1533	69	597	31	703	99
2	1112	84	661	27	497	107
3	735	47	778	29	443	76
4	894	56	882	28	645	107
5	1149	71	616	36	635	107
6	900	73	1130	46	642	160
7	995	47	1519	29	1372	184
8	980	65	587	33	903	133
9	809	48	561	7	1001	134
10	907	68	588	26	886	125
Average	1001	63	792	29	774	123
%RSD	22.5	20.3	39.4	33.4	35.7	25.5

Table 46. Lead and chromium content in type 2 grit spiked to 200 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	117	100	77	33	130	77
2	180	94	112	46	119	114
3	155	134	96	33	107	82
4	161	112	125	29	149	86
5	262	152	67	23	111	80
6	182	129	107	32	139	66
7	213	115	98	23	122	77
8	316	121	105	40	97	93
9	163	111	87	39	103	89
10	148	108	141	36	122	93
Average	196	118	102	33	120	87
%RSD	27.6	14.5	21.6	21.8	13.6	14.5

Table 47. Lead and chromium content in type 2 grit spiked to 50 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	93	126	31	47	53	199
2	86	137	41	33	57	172
3	88	146	27	45	47	124
4	80	108	36	41	54	177
5	83	136	27	39	56	135
6	93	137	19	27	60	179
7	86	103	28	21	52	190
8	74	100	20	27	54	161
9	75	102	19	28	49	151
10					45	209
Average	84	122	28	34	53	170
%RSD	8.2	15	27.8	26.7	8.8	16.0

Table 48. Lead and chromium content in type 2 grit spiked to 0 mg/kg of lead with ashed bridge paint.

Replicate	ASTM D3335		NIOSH 7082		EPA 3050	
	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr	mg/kg Pb	mg/kg Cr
1	36	32	38	39	61	91
2	41	57	35	37	59	99
3	61	26	27	39	62	116
4	32	75	33	43	62	114
5	67	34	14	27	72	112
6	47	57	37	23	61	110
7	56	28	28	37	58	117
8	27	48	14	27	64	105
9	35	43	41	39	59	117
10			18	31	62	92
Average	45	44	28	34	62	107
%RSD	31.2	36.8	35.4	19.5	6.4	9.4

Table 49. Lead content in type 2 grit spiked to 1000 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	839	817	801
2	648	826	793
3	773	757	759
4	816	738	790
5	626	783	896
6	834	869	807
7	851	708	800
8	700	753	752
9	607	737	697
Average	744	691	788
%RSD	13.3	7.3	6.8

Table 50. Lead content in type 2 grit spiked to 200 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	257	163	216
2	275	173	258
3	273	134	227
4	249	160	225
5	278	176	245
6	287	142	254
7	254	156	243
8	251	152	246
9	257	168	267
10		179	234
Average	265	160	242
%RSD	5.2	9.2	6.6

Table 51. Lead content in type 2 grit spiked to 50 mg/kg of lead with NIST 1579a paint.

Replicate	ASTM D3335	NIOSH 7082	EPA 3050
	mg/kg Pb	mg/kg Pb	mg/kg Pb
1	65	79	91
2	54	71	98
3	68	58	97
4	47	48	100
5	59	71	87
6	58	68	91
7	56	54	98
8	58	62	83
9	52	63	85
10	58	64	88
Average	58	64	92
%RSD	10.4	14.2	6.6

TOTAL LEAD VERSUS LEACHABLE LEAD

Total lead and leachable lead do not correlate. Many agencies have tested numerous samples that contain very high levels of total lead (well over 10 percent, i.e., 100 000 mg/kg) that do not leach lead above 5 mg/kg, the RCRA maximum in order for a waste to be non-hazardous. However, if it could be established that there was a minimum lead content that would assist in classifying the waste, this would be of use to the highway agencies. Total lead analysis could be performed quickly on a sample of debris to indicate the probability of the waste being classified as hazardous.

In order to determine if this was possible, a series of experiments were performed to evaluate the leaching characteristics of different lead paints and compounds in various matrixes. Each is briefly described below.

TEST 1

Purpose:	Determine the effect of abrasive on a lead known to be 100 percent leachable.
Procedure:	100 g of abrasive were added to new polypropylene containers. Various amounts of 1000-mg/kg lead nitrate (a purchased 1000-mg/kg reference solution) was added to the abrasive. The samples were thoroughly mixed and allowed to air dry. When the samples were dry, they were mixed again by shaking the container. 1-g grab samples were withdrawn from the container and the total lead was determined using the ASTM D3335 procedure. A standard TCLP test was performed on the remaining abrasive lead mixture.
Abrasive:	A mineral sand, a coal slag, and a silica sand were tested. Steel abrasives were not tested, due to known interferences.
Discussion:	These data indicated that even under ideal conditions, and in order to obtain a leachable lead greater than 5 mg/kg in a typical abrasive, the minimum total lead content is about 150 mg/kg and may be somewhat abrasive-sensitive.
Conclusion:	To obtain a leachable lead greater than 5 mg/kg, the absolute minimum lead in an abrasive appears to be in the 150-mg/kg range. Abrasive type may affect minimums.

Results are reported in table 52.

Table 52. Results of tests to determine effect of abrasive on a lead known to be 100 percent leachable.

Theoretical Spiked Value	Mineral Sand		Coal Slag		Silica Sand	
	Total Lead, mg/kg	Leachable Lead, mg/kg	Total Lead, mg/kg	Leachable Lead, mg/kg	Total Lead, mg/kg	Leachable Lead, mg/kg
0	16	BDL[1]	12	BDL	7	BDL
50	57	0.6	42	1.7	63	1.9
100	108	1.6	91	3.6	105	3.8
150	172	2.6	137	5.3	169	5.9
200	185	3.8	175	7.7	212	7.8
250	245	6.1	231	9.1	254	10.1

[1] Below detectable limits.

TEST 2

Purpose:	Using lead paints to spike samples determines the minimum total lead required to result in leachable lead greater than 5 ppm.
Procedure:	Sufficient lead-based paint was added to various abrasives to result in mixtures that have theoretical total lead concentrations of 250 mg/kg, 500 mg/kg, 1000 mg/kg, 1500 mg/kg, 2000 mg/kg, 2500 mg/kg, and 5000 mg/kg. They were mixed by dry tumbling in a TCLP tumbler for 30 min. 1-g grab samples were withdrawn from the container and the total lead was determined using ASTM Method D3335. A standard TCLP test was performed on the remaining abrasive lead mixture.
Abrasive:	A mineral sand, a coal slag, and a silica sand were tested. Steel abrasives were not tested due to known interferences.
Paints:	Three paints were evaluated: NIST 1579a, milled bridge paint, and ashed bridge paint. All three were described previously in this appendix.

Test results are reported in table 53.

Table 53. Results of tests using lead paints to spike samples to determine total lead required to result in leachable lead greater than 5 ppm.

Paint Type	Spiked Value mg/kg	Mineral Sand (mg/kg)		Coal Slag (mg/kg)		Silica Sand (mg/kg)	
		Total Lead[1]	Leachable Lead	Total Lead[1]	Leachable Lead	Total Lead[1]	Leachable Lead
NIST 1579a	250	169	7.5	165	10	177	11
NIST 1579a	500	294	15	302	18	362	19
NIST 1579a	1000	689	28	584	33	813	27
NIST 1579a	1500	942	40	996	45	1829	53
NIST 1579a	2000	1472	54	1370	57	1583	51
NIST 1579a	2500	1717	65	1848	66	2691	72
NIST 1579a	5000	3600	103	3949	100	4808	89
Milled Bridge	250	237	0.7	190	1.0	365	2.2
Milled Bridge	500	305	1.1	225	2.2	398	2.4
Milled Bridge	1,000	539	2.3	1250	3.6	1331	4.9
Milled Bridge	1500	1127	4.1	164	4.4	1606	6.9
Milled Bridge	2000	1777	4.5	1795	6.3	1825	8.2
Milled Bridge	2500	2417	5.9	2441	8.4	2774	9.1
Milled Bridge	5000	6593	13	550	17	5217	18
Ashed Bridge	250	Lab Error		252	9	232	14
Ashed Bridge	500	287	16	313	22	993	40
Ashed Bridge	1000	600	30	1012	41	836	41
Ashed Bridge	1500	1279	50	1269	54	1012	56
Ashed Bridge	2000	1720	71	1181	77	1193	75
Ashed Bridge	2500	2500	85	2041	88	2117	103
Ashed Bridge	5000	1447	154	Lab Error	189	5638	181

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[1] Per ASTM D3335.

DISCUSSION

It is clear from these data that the particle size of the lead in the waste affected the leachable lead content. The paints that were either ashed or finely ground had significantly higher values than the paint taken from the bridge. What is not known is how the simulated paint compares to paint from actual structures. (See test 3.) These data suggested that for the milled bridge paint, the minimum total lead needed to result in a greater leachable lead concentration than 5 mg/kg was approximately 1500 mg/kg. Paints that had a very small particle size or have been ashed have minimums that are much closer to the theoretical minimum of 100 mg/kg.

TEST 3

Purpose: Determine if the laboratory mill paint is similar to an actual field sample using the same abrasive.

Procedure: Debris from a bridge project was diluted with the same mineral abrasive used on the project. Total lead (ASTM D3335) and TCLP leachable lead were measured for each sample.

Results are reported in table 54.

Table 54. Test results to determine if laboratory mill paint was similar to actual field sample using the same abrasive.

Debris, %	Abrasive Added, %	Total Lead, mg/kg	Leachable Lead, mg/kg
90	10	20 106	65.1
70	30	10 032	56.9
50	50	11 737	24.1
35	65	7142	21.4
30	70	6140	16.6
25	75	4854	12.6
20	80	2729	10.3
15	85	1729	4.8
10	90	1652	4.7
9	91	1589	3.4

DISCUSSION

These data indicated that the laboratory-milled bridge paint had about the same degree of leachability as the field sample. The minimum total lead that resulted in a leachable lead greater than 5 mg/kg in the field sample was in the 1500-mg/kg range. There was not sufficient data to make any absolute statements about minimum total lead concentration that would result in a hazardous waste in bridge paints.

TEST 4

Introduction: It is well known that elemental iron will render lead-containing wastes non-hazardous when leachable lead content is measured by the TCLP tests. The form and amount of the iron-containing material are not as well understood.

Purpose: Determine the amount and type of iron or steel grit needed to cause a waste that leaches at a high level to leach at values below 5 mg/kg.

Procedure: Steel grit was added to a known hazardous waste and the TCLP procedure was performed on the mixture.

Waste: Two wastes with leachable lead levels typically encountered in the highway industry were used. Both had a mineral sand as the abrasive.

Tested Grits: Five different grits were tested:

- G-80-1 Typical G-80 steel grit.
- G-80-2 Typical G-80 steel grit from a different supplier.
- G-80-3 Typical G-80 steel grit from a third supplier.
- G-40 Typical G-40 steel grit.
- S-40 Typical shot grit mixture similar in size to G-40.

Results are reported in table 55.

Table 55. Leachable lead content as a function of type and amount of iron.

	Grit addition, percent by weight													
	Grit Type	0	1	2	3	4	5	6	7	8	9	10	11	12
Waste 1	G-80-1	68	57	12.8	1.4	0.7	0.5	0.4	0.4	0.3	0.4	0.3	0.3	0.3
Waste 1	G-80-2	68	65	29	3.3	1.4	1	0.8						
Waste 1	G-80-3	68	62	48	12	2.9	1.7	0.5	0.4	0.7				
Waste 1	G-40	68	59	43	27	16	8.6	6	3.6	2.4	1.9	1.3		
Waste 2	G-80-1	35	26.7	6.4	3	1.9	1.6	0.8	0.3	0.2	0.1	0.08	0.3	0.3
Waste 2	G-80-2	35	26.6	5.4	4.4	3.1	3	3	2.5	1.8	1.1	0.5		
Waste 2	G-40	35	26	21	20	19.8	10.2	4.1	2.7	1.4	1.1	0.6		
Waste 2	S-40	35	34	32	30	29.3	23	15.5	11	7.5	8	8.8	8.8	8.8

DISCUSSION:

It was clear from the above data that the smaller the particle size, the more efficient the grit was at stabilizing a lead waste. In addition, not all steel grit products were effective in reducing the leachable lead content to below the regulatory limit. However, based on the above and 3 years of testing wastes stabilized with iron, 6 to 10 percent of almost any, but not all, grit will stabilize waste sufficiently to pass a TCLP test. Tests should be done to confirm the percentage of grit in the waste (easily done with magnetic separation techniques) and its suitability to reduce leachable lead.

TEST 5

Introduction: There has been and still is considerable debate among interested parties on the suitability of blast additives and stabilization technologies. It became apparent in this research that it was necessary to perform at least a limited study to give guidance to highway agencies on long-term stability of wastes. Some agencies were exclusively using steel grit additions to the abrasive, or a steel grit addition was being used by contractors. It is known that steel grit stabilizes lead only when it is in its metallic form. When it rusts, it does not stabilize lead waste. How long it stabilizes is unknown.

Purpose: Determine the long-term stability of wastes from typical bridge projects using available stabilization techniques and various testing procedures.

Procedure: There are two known long-term leaching procedures that are supposed to determine the long-term leaching of wastes. These are the Multiple Extraction Procedure in EPA Method 1320 found in SW-846, chapter 6, and an ASTM Method D4874. Besides these procedures, a third method was developed by the laboratory. The simulated landfill procedure is reported in detail below. The other methods are standard published procedures.

1000-g samples of waste were placed in a 12.7-cm by 22.9-cm (5-in by 9-in) tub. The waste was about 2.5 cm (1 in) thick in the tub. In the bottom of the tub was a series of fifteen 1-mm holes. The holes were covered with paper towels that acted as a filter. The waste was exposed to 5000 mL of various extraction fluids over a period of 3 days. The extraction fluid was collected and analyzed for total lead content. This 5000-mL addition was repeated on the same waste to relate leaching with time of exposure. In addition, at each time interval, a small amount of material was removed and the TCLP leaching procedure was performed on each sample.

Leaching Solutions: The Multiple Extraction Procedure used only the fluids required by the procedure.

ASTM Method D4784 was performed using TCLP Solution I.

Three leaching solutions were used in the simulated landfill tests:

- TCLP Solution 1—a buffered acetic acid solution with a pH of 4.93.
- Multiple Extraction Fluid—a 60/40 blend of sulfuric acid and nitric acid solution with a pH of 3.0.
- De-ionized water.

Waste: Spent abrasive from which the iron grit used as a stabilizing agent had been removed. The abrasive used was a mineral sand. Once the grit was removed, the material leached about 80 mg/kg in the TCLP procedure.

Stabilizing Agents: Four stabilizing strategies were evaluated:

- Portland Cement—The waste was combined with 25 percent by weight portland cement and 12.5 percent water. The mixture was allowed to cure for at least 28 days before testing. Once the mixture had cured, it was crushed so that it was in compliance with TCLP particle size requirements, e.g., passing a 0.95-cm (3/8-in) screen.

- Portland Cement and Iron Grit—6 or 10 percent G-40 iron grit was added to the debris and then the mixture was further stabilized with portland cement as above.

- Steel Grit—6 or 10 percent G-40 steel grit was added without any further stabilization.

- Proprietary Additive—15 percent of a proprietary stabilizing agent was added without any further stabilization.

Results are reported in tables 56 through 59.

Table 56. Multiple extraction procedure results.

Extraction Cycle	No Stabilizer	10% Steel Grit	6% Steel Grit	25% Portland Cement	6% Steel Grit and 25% Portland Cement	15% Proprietary Additive
1	80	0.72	1.3	0.13	0.26	0.18
2	18.4	0.35	1.3	0.19	0.12	0.08
3	20.1	0.07	1.5	0.38	0.13	0.08
4	15.7	0.18	0.7	0.33	0.8	2.1
5	17.8	BDL[1]	1.1	0.4	0.9	1.1
6	15.4	1.2	2.1	0.27	0.8	BDL
7	15.8	1.7	3	0.27	0.15	0.15
8	15.6	2.4	3.7	0.3	0.14	0.09
9	15.6	3	4.3	0.23	0.8	0.09
10	14.3	3.3	7.7	0.17	BDL	BDL
11	9.4	3.9	7.6	0.28	0.1	BDL

[1] Below detectable limits.

Table 57. ASTM Method D4874 results.

Stabilized with 25% Portland Cement		Stabilized with 10% Steel Grit and 25% Portland Cement		Stabilized with 10% Steel Grit		Stabilized with 15% Proprietary Additive	
Days from start of test	Lead content of leachate, mg/kg	Days from start of test	Lead content of leachate, mg/kg	Days from start of test	Lead content of leachate, mg/kg	Days from start of test	Lead content of leachate, mg/kg
1	6.4	1	3.4	1	0.09	1	28
2	6.6	4	3.8	2	BDL[1]	2	26
3	6.6	5	3.2	3	BDL	3	21.5
4	7	6	5.1	6	BDL	4	6.3
5	6.2	7	4.4	7	BDL	7	20
6	6.6	11	3	8	BDL	8	10.5
7	5.9	12	1.3	9	BDL	9	8
		19	1.8	13	BDL	10	6.1
		20	1.7	14	BDL	14	6.6
		21	1.3	21	BDL	15	10.3
		25	1.1	22	0.12	22	8.4
		26	0.9	23	BDL	23	8.7
		32	1.2	27	BDL	24	7.2
		33	1.5	34	0.48	28	11
		34	0.6	35	BDL	29	4.2
		35	0.22	36	0.08	34	8.4
		36	0.18			35	11
						36	0.17

[1] Below detectable limits.

Table 58. Simulated landfill results.

	Fluid	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
		9-14-93	9-17-93	9-21-93	9-24-93	9-29-93	10-7-93	10-17-93	10-22-93	11-3-93
		Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg	Leached Lead, mg/kg
25% PC +10% SG	MEP	0.57	BDL	0.09	BDL	BDL	0.09	0.19	BDL	BDL
25% PC	MEP	BDL[1]	0.57	BDL	BDL	BDL	BDL	0.26	BDL	BDL
10% Steel Grit	MEP	3.5	3.4	0.37	3.5	9.5	8.4	6.4	3.9	17.2
15% Prop Additive	MEP	Lab error	0.2	BDL	BDL	BDL	0.67	0.59	0.1	11.1
25% PC +10% SG	TCLP 1	BDL	0.9	1.7	BDL	BDL	0.28	1.3	2.3	1.4
25% PC	TCLP 1	BDL	2.7	2.2	6.7	0.26	0.25	0.59	BDL	0.08
10% Steel Grit	TCLP 1	3.5	3.8	1.2	0.08	2.4	6.3	5.9	5.2	4.7
15% Prop Additive	TCLP 1	2.6	8.7	22.4	24.5	28.8	18	16	9.9	9.6
25% PC +10% SG	DI H_2O	BDL	0.43	0.18	0.15	BDL	BDL	0.08	BDL	BDL
25% PC	DI H_2O	BDL	0.26	BDL	BDL	BDL	BDL	0.25	BDL	BDL
10% Steel Grit	DI H_2O	BDL	0.18	BDL	BDL	BDL	BDL	0.16	BDL	BDL
15% Prop Additive	DI H_2O	BDL	0.62	0.2	BDL	BDL	0.67	0.95	0.17	BDL

[1] Below detectable limits.

Table 59. TCLP leachable lead on grab samples from the simulated landfill test.

		Sample 1	Sample 3	Sample 5	Sample 6	Sample 8	Sample 9
		9-14-93	9-21-93	9-29-93	10-7-93	10-22-93	11-3-93
	Fluid	Leachable lead, mg/kg	Leachable lead, mg/kg	Leachable lead, mg/kg	Leachable lead, mg/kg	Leachable lead, mg/kg	Leachable lead, mg/kg
25% PC +10% SG	MEP	0.26	0.13	0.1	BDL	0.24	BDL
25% PC	MEP	BDL[1]	0.08	BDL	BDL	0.14	BDL
10% Steel Grit	MEP	0.5	1.2	1.1	7	0.67	2.8
15% Prop Additive	MEP	BDL	0.2	BDL	BDL	1.7	BDL
25% PC +10% SG	TCLP 1	0.07	BDL	BDL	BDL	BDL	BDL
25% PC	TCLP 1	0.82	0.1	BDL	BDL	BDL	BDL
10% Steel Grit	TCLP 1	0.16	1.3	0.75	0.94	1.2	1.9
15% Prop Additive	TCLP 1	0.08	BDL	BDL	BDL	BDL	0.07
25% PC +10% SG	DI H_2O	0.26	0.032	BDL	BDL	BDL	BDL
25% PC	DI H_2O	0.14	BDL	0.19	0.2	BDL	BDL
10% Steel Grit	DI H_2O	0.17	1.6	3.2	20	6.4	8.3
15% Prop Additive	DI H_2O	0.45	1	0.12	BDL	BDL	BDL

[1] Below detectable limits.

TEST 6

Introduction: Laboratories use either atomic absorption (AA) or Inductively Coupled Plasma atomic absorption (ICP) to perform the actual lead measurement. There is concern that chemical interferences may exist that would give false results by one or the other procedure.

Purpose: Compare lead measurements on the same sample using AA and ICP equipment.

Procedure: Two paints were used—the NIST 1579a and the ashed bridge paint. All samples were spiked between 0 and 1000 mg/kg in two steel grits and a mineral sand. Since ICP was used on all other tests, various samples were simply analyzed on the AA also. For brevity, the mean of all 9 or 10 samples is reported and, for convenience, the ICP results are copied from the previous sections.

Equipment: Perkin Elmer Plasma 40 ICP
Perkin Elmer 3110 AA

Test results are reported in table 60.

Table 60. Comparison of results obtained on ICP and AA.

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
NIST	Steel Grit Type I	1000	D3335	1226	5.4	1003	6
		200	D3335	278	2.9	294	5.7
		50	D3335	107	5.4	134	8
		0	D3335			132	10.1
		1000	7082	954	4.3	837	4.4
		200	7082	209	8.5	220	8.6
		50	7082	65	6.9	96	5.9
		0	7082	27	10.2	71	4.6
		1000	3050	1093	1.6	855	2.8
		200	3050	228	5.2	222	4.5
		50	3050	87	8	133	4.4
		0	3050	41	6.5	126	2.6

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
NIST	Steel Grit Type II	1000	D3335	1012	13.5	744	13.3
		200	D3335	240	5.1	265	5.2
		50	D3335	60	12.6	58	10.4
		0	D3335	11.5	58.2	44.7	31.2
		1000	7082	1041	7.6	768	7.3
		200	7082	184	9.1	160	9.2
		50	7082	63	14.2	64	9.1
		0	7082	10	26.6	29	35.4
		1000	3050	1057	5.6	788	6.8
		200	3050	254	8	241	6.6
		50	3050	60	8	92	6.6
		0	3050	13	7.7	62	6.4

Table 60. Comparison of results obtained on ICP and AA (continued).

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
NIST	Mineral Sand	1000	D3335			1143	7.8
		200	D3335	222	9.2	187	9.4
		50	D3335	69	9.8	54	13
		0	D3335	23	21.7	11	28.4
		1000	7082	1171	4.1	1030	4.6
		200	7082	210	5	182	5
		50	7082	48.2	12.7	43.5	11.6
		0	7082	6.1	23	7.4	12.2
		1000	3050	971	8	880	7.9
		200	3050	202	7.2	182	7.2
		50	3050	53	5.9	50	7.8
		0	3050				

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
Ashed Bridge Paint	Steel Grit Type I	1000	D3335	459	29.4	423	26.6
		200	D3335	145	6.2	181	4.8
		50	D3335	70	3.4	116	5.5
		1000	7082	383	16.1	320	15.3
		200	7082	124	14.4	135	11.5
		50	7082	46	7.7	68	7.9
		1000	3050	503	632	420	60
		200	3050	128	22	172	15.3
		50	3050	64	4.3	121	3.8

Table 60. Comparison of results obtained on ICP and AA (continued).

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
Ashed Bridge Paint	Steel Grit Type II	1000	D3335	1041	23.7	1001	22.5
		200	D3335	178	33.6	196	27.5
		50	D3335	35	19.8	84	8.2
		1000	7082	935	37.7	792	39.4
		200	7082	123	21.8	102	21.6
		50	7082	31	25.2	28	27.8
		1000	3050	892	33.6	774	35.7
		200	3050	107	21.7	120	13.6
		50	3050	43	9.3	53	8.8

Paint	Abrasive	Spiked Value mg/kg	Preparation Method	AA mg/kg	AA % RSD	ICP mg/kg	ICP % RSD
Ashed Bridge Paint	Starblast	1000	D3335	922	14.7	892	14
		200	D3335	206	25.5	205	26.5
		50	D3335	60	14.5	57	14.9
		1000	7082	864	7.2	812	11
		200	7082	163	18.4	155	17.6
		50	7082	48	20.7	44	18.3
		1000	3050	971	12.7	931	12.9
		200	3050	171	16.7	162	17.3
		50	3050	53	54.4	49	52.9

DISCUSSION

The results indicated that most of the variation was due to sample variability. Generally,the values and percent RSD were similar for most samples. There were problems with some steel grits and lead detection, regardless of the test method or analytical instrument.

CONCLUSION

Either instrument was suitable for detection of lead in steel grits at or near 1000 mg/kg. At low values, less than 100 mg/kg, the AA was a better choice when steel grits are the sample matrix.

APPENDIX B. MONITOR COMPARISON

INTRODUCTION

Performing air monitoring on a project to measure lead and particulate emissions is required to demonstrate that Clean Air Act (CAA) regulations are being met. There are two regulations that could apply to bridge-painting projects. 40 CFR 50.12 regulates the amount of lead that can be in the air to 1.5 $\mu g/m^3/24$ h averaged over 90 days. 40 CFR 50.6 regulates the amount of particulate matter less than 10 μm (respirable dust, hence the name PM_{10}) to 150 $\mu g/m^3/24$ h. Current CAA regulations require the use of Total Suspended Particulate (TSP) monitors to monitor lead emissions and PM_{10} monitors for particulate matter. TSP and PM_{10} monitors are not easy to maintain and operate. If some other simple monitor or other method could be found that correlates to the TSP and PM_{10} monitors and methods, EPA would accept the equivalent alternative. EPA has provided for this in 40 CFR 53, Ambient Air Monitoring Reference and Equivalent Methods. However, it would be an expensive and time-consuming study to do all the items that are required in this regulation. Before a formal correlation study could be initiated, it would be necessary to obtain preliminary information on the probability of correlation of the chosen methods. To that end, two series of tests using the same equipment were performed. The first series of tests was conducted on various lead paint removal operations. Four different type monitors were placed 15.25 m (50 ft) downwind about 1.3 to 2 m (4 to 6 ft) apart while lead paint was being removed. In the second test, monitors were placed in a 15- by 15-m (50- by 50-ft) area—all equidistant from an airborne lead source.

TEST EQUIPMENT

Four monitors were chosen for comparison purposes. They are described as follows:

PM_{10} Monitor	Model #7625-16H Manufactured by Greseby-Andersen. Instrument was calibrated in accordance with the manufacturer's written procedures supplied with the instrument. Flow rate was set to 1.1 m^3/min (40 ft^3/min).
TSP Monitor	Model #5323-2H Manufactured by Greseby-Andersen. Instrument was calibrated in accordance with the manufacturer's written procedures supplied with the instrument. Flow rate was set to 1.1 m^3/min (40 ft^3/min).
10-L Pump	Model #1531 Manufactured by Gast. Instrument was calibrated using a Sensidyne EZ cal 2 Digital Flowmeter in accordance with the manufacturer's instructions. The flowmeter was calibrated to NBS traceable standard MERIAM 719980. The flow rate of the pump was adjusted to 10 L/min.
2-L Pump	Model GilAir-5 Manufactured by Gilian. Instrument was calibrated using a Sensidyne EZ cal 2 Digital Flowmeter in accordance with manufacturer's instructions. The flowmeter was calibrated

to NBS traceable standard MERIAM 719980. The flow rate of the pump was adjusted to 2 L/min.

TEST PROCEDURES

Test 1 Procedure

During the routine monitoring of various containment methods and lead-removal techniques, all four monitors were placed as described. Lead determinations in the TSP and PM_{10} filters were done in accordance with EPA procedures contained in 40 CFR 50, Appendix G, with the exception that an Inductively Coupled Plasma (ICP) instrument was used to qualitatively measure lead instead of the Atomic Absorption (AA) instrument called for in the method. This substitution was considered insignificant for these tests. Lead collected on the filters using the 2-L/min and 10-L/min pumps were measured in accordance with NIOSH 7082. The results are presented in table 61.

Test 2 Procedure

A 15.25- by 15.25- by 4.5-m (50- by 50- by 15-ft) area was contained below a bridge. The containment fabric used was a woven fabric coated with polyethylene. The fabric was impermeable to air. A high-air-volume, high-speed, 25.4-mm (20-in) fan with 277.51 m^3/min (9,800 CFM) output in free air was placed in one corner of the area. The fan was positioned so that the discharged air was directed up toward the center of the contained area to distribute lead-contaminated spent abrasive into the air. Once every hour, small amounts of lead were dispersed into the air by slowly sprinkling a known amount of lead-containing spent abrasive in front of the fan. The monitors were spaced 2.5 m (8 ft) apart in an arc 13.75 m (45 ft) away from the fan. Each hour the monitors were moved to an adjacent position; thus, at the end of 4 h, all monitors had been in all positions. The duration of the test was either 4 or 8 h. All filters were analyzed in accordance with EPA procedures or NIOSH procedures. Results of lead analyses are reported in table 62. Results of particulate measurements are reported in table 63.

Table 61. Comparison of air-monitoring devices during surface preparation on a bridge.

Removal Method	Test Date	Duration (h)	Lead Concentration, $\mu g/m^3$			
			2-L/min Pump	10-L/min Pump	TSP Monitor	PM_{10} Monitor
Mineral Sand	3-26-93	4	6.25	1.25	12.6	2.1
Mineral Sand	3-29-93	4	PF[1]	2.08	7.7	PF
Mineral Sand	4-06-93	3.5	5.2	1.8	7.7	1.9
Mineral Sand	4-27-93	2.75	9.1	4.5	15.2	5.6
Mineral Sand	5-26-93	2.5	10.3	4.2	<0.6	<0.6
Steel Grit	4-13-93	2	8.25	5	1.9	<0.7
Steel Grit	4-14-93	2	10	2.2	3.1	3.8
Steel Grit	4-21-93	2	6.7	1.2	2.7	<0.7
Steel Grit	4-23-93	2	13.3	PF	<0.7	<0.7
Elec. Power Tools	5-10-93	3	3.5	4.2	<0.5	<0.5
Air Power Tools	5-14-93	3	BDL[2]	BDL	<0.5	<0.5
Chemical Stripping	7-01-93	2.5	4.1	3.4	<0.7	<0.7
Vacuum Blasting	7-15-93	2.2	Not tested	Not tested	<0.6	<0.6

[1] Pump failure.
[2] Below detectable limits.

Table 62. Comparison of lead concentration collected by different air monitors in a controlled test.

TRIAL	Duration	Amount of Lead Introduced	Lead Concentration $\mu g/m^3$			
	Test time in hours	Grams of spent abrasive per hour	2-L/min Pump	10-L/min Pump	TSP Monitor	PM_{10} Monitor
Trial 1	4	25	2	2	1.5	0.52
Trial 2	4	100	2	1	4.9	2.2
Trial 3	4	200	9	6	10.5	6.4
Trial 4	8	300	10	12	57.9	18.9

Table 63. Comparison of particulates collected by different air monitors in a controlled test.

TRIAL	Duration	Amount of Lead Introduced	Total Collected Particulate	Total Collected Particulate	
	Total test time in hours	Grams of spent abrasive per hour	TSP $\mu g/m^3$	PM_{10} $\mu g/m^3$	Ratio of weights
Trial 1	4	25	133	96	1.38 : 1
Trial 2	4	100	140	85	1.65 : 1
Trial 3	4	200	195	100	1.94 : 1
Trial 4	8	300	620	271	2.29 : 1

DISCUSSION

It does not appear that the four instruments correlate well with each other based on the tests performed. Relying on PM_{10} monitors for compliance with CAA requirements for both total particulates and lead was found to be unreliable, as the lead collected by the PM_{10} monitor was about half of that collected by the TSP monitor.

2- and 10-L pumps did not have sufficient precision below 4 $\mu g/m^3$ to comply with 40 CFR 53.33 requirements. Fifteen percent precision is not achievable between 0.5 to 4 $\mu g/m^3$ with this equipment. In addition, these pumps will probably be out of compliance with the comparability requirement. The maximum allowable difference is 20 percent from the reference method (TSP). The data indicated that not only the 2- and 10-L equipment, but even the PM_{10} monitors will not meet this requirement for measuring lead in the air.

APPENDIX C. SURFACE PREPARATION

INTRODUCTION

There are many alternative surface preparation methods available for the removal of bridge paint. Each of these may be touted by some as being the "best" or "most economical" or "environmentally safe" or "environmentally risk-free." Each system has applications where that particular method produces the best results, while at the same time there are applications where the same system may produce the poorest results. The tests described in this appendix are presented to give guidance concerning the production rates that can be expected on bridges, the lead levels that can be expected to be released to the environment, and the levels of lead to which workers may be exposed.

The five methods that were evaluated are:

- Abrasive blasting using steel grit.
- Abrasive blasting using mineral sand.
- Vacuum blasting.
- Power-tool cleaning.
- Chemical stripping.

All systems were evaluated on a typical freeway overpass-type structure. Many individual items were being monitored while the trials were being conducted. Only the surface preparation is discussed in this appendix. Containment and ventilation details can be found in appendixes E and F. The test setup, production rates, and monitoring results will be described for each system tested.

TEST EQUIPMENT COMMON TO ALL TESTS

All the work was performed on a typical four-lane freeway overpass. The bridge was located on private property in an industrial park. The bridge was 15 m (50 ft) wide, 33.5 m (110 ft) long, and 4 m (13.5 ft) high. A deck was in place for all tests. Containments were both parallel and perpendicular to the beams. Containments were either 2.13 m (7 ft) tall or 4.27 m (14 ft) tall.

Two sets (PM_{10} and TSP) of air monitors were located 15 m (50 ft) downwind and upwind of the containment to measure air quality when work was performed.

TEST 1: ABRASIVE BLASTING WITH RECYCLABLE STEEL ABRASIVE

EQUIPMENT AND CONDITIONS:

Ipec Alpha 2000	Steel Grit Recycling Unit
Air Compressor	21.2 m^3/min (750 CFM)

Blast Hose	30.5 m (100 ft)
Blasting Nozzle	#8 Venturi
Blast Pressure	7 kgf/cm^2 (100 lbf/in^2) at the nozzle
Abrasive	New G-40 steel grit
Surface Cleanliness	SSPC-SP 10 (Near-White)

All equipment was operated within normal parameters. The machine was set up by personnel familiar with its operation. Blasters had relatively easy access to all surfaces.

PROCEDURES:

Each trial was conducted for 2 h. The limitation was the amount of abrasive available. At the end of 2 h, all the abrasive was cleaned up and passed through the reclaimer.

Each trial used at least 0.76 mm (0.03 in) of negative air pressure inside containment.

Personal air samplers on the blasters were changed each hour. On 2 d, tests were performed concurrently both inside and outside of the blaster's hood.

Table 64. Abrasive blasting with recyclable steel abrasive.

	Test 1	Test 2	Test 3	Test 4
Test Date	4-14-93	4-21-93	4-13-93	4-23-93
Containment Height	2.13 m (7 ft)	4.27 m (14 ft)	2.13 m (7 ft)	4.27 m (14 ft)
Orientation to Beams	Perp[1]	Perp	Parallel	Parallel
Wind, km/h (mi/h)	25.75 to 41.84 (16 to 26)	16.09 (≈10)	11.27 (≈7)	14.48 (≈9)
Worker Pb Exposure 1st h, $\mu g/m^3$	13 222	8511	22 412	4258
Worker Pb Exposure 2nd h, $\mu g/m^3$	16 883	3917	16 534	4250
Avg Worker Pb Exposure, $\mu g/m^3$	15 314	5886	19 667	4254
Inside Hood, $\mu g/m^3$		<4		7
PM_{10} Upwind Particulate, $\mu g/m^3$	NT[2]	5	113	17.5
PM_{10} Downwind Particulate, $\mu g/m^3$	NT	0.83	114	1.7
PM_{10} Upwind Pb, $\mu g/m^3$	BDL[3]	BDL	BDL	BDL
PM_{10} Downwind Pb, $\mu g/m^3$	4.2	BDL	BDL	BDL
TSP Upwind Pb, $\mu g/m^3$	BDL	BDL	BDL	BDL
TSP Downwind Pb, $\mu g/m^3$	3.4	3	8.5	2.1
Surface Area Cleaned (m^2/h (ft^2/h))	11.89 (128)	8.69 (93.5)	11.8 (127)	7.34 (79)

[1] Perp = Perpendicular

[2] NT = Not Tested

[3] Below Detectable Limits

Average area cleaned = 9.94 m^2/h (107 ft^2/h). Average worker lead exposure = 11 280 $\mu g/m^3$.

During the test, the blaster commented repeatedly that the visibility inside containment was much better when using steel grit than when using disposable abrasives.

TEST 2: ABRASIVE BLASTING WITH DISPOSABLE ABRASIVE

EQUIPMENT:	Conventional 136-kg (300-lb) blast pot.
	21.24 m^3/min (750 CFM) air compressor.
	30.5-m (100-ft) blasting hose; 7 kgf/cm^2 (100 lbf/in^2) of pressure was maintained at the nozzle.
	#6 Venturi blasting nozzle.
	A mineral sand abrasive was used.

All equipment was operated within normal parameters. The machine was set up by personnel familiar with its operation. The blaster had relatively easy access to all surfaces.

The time for each trial was variable, depending on weather conditions and available surface area.

All surfaces were blasted to an SSPC-PC10, Near-White condition.

Each trial used at least 0.76 mm (0.03 in) of negative air pressure inside containment.

Personal air samplers on the blaster were changed each hour. On 2 d, tests were performed both inside and outside of the blaster's hood.

One test condition, namely a 4.27-m-high (14-ft-high) containment perpendicular to the beams, could not be performed due to the lack of availability of a large dust collector.

Test 1 on March 26, 1993, was fraught with first-day startup problems. It should not be (and was not) used to obtain and calculate production data. A direct comparison between the steel grit and mineral sand abrasive productivity can only be made if adjustments for nozzle size are taken into account since different nozzle sizes were used.

Test 5 was a special containment. It consisted of a containment within a containment similar to the process used by the Illinois Department of Transportation. The working containment was set up inside another large contained area measuring 15 by 15 m (50 by 50 ft). Ambient air monitoring was performed outside the larger containment.

Table 65. Abrasive blasting with disposable abrasive.

	Test 1	Test 2	Test 3	Test 4	Test 5
Test Date	3-26-93	3-29-93	4-27-93	4-6-93	5-26-93
Test Duration in hours	4	4	2.75	3.5	2.5
Containment Height	2.13 m (7 ft)	2.13 m (7 ft)	2.13 m (7 ft)	4.27 m (14 ft)	2.13 m (7 ft)
Orientation to Beams	Perp[1]	Perp	Parallel	Parallel	Parallel
Wind, km/h (mi/h)	NT[2]	6.44 (≈4)	12.87 (≈8)	14.48 (≈9)	0
Worker Pb Exposure 1st h, μg/m³	6327	15 100	19 777	14 875	12 400
Worker Pb Exposure 2nd h, μg/m³	1400	13 033	12 500	444	5622
Worker Pb Exposure 3rd h, μg/m³	4508	10 566	15 166	15 000	2884
Worker Pb Exposure 4th h, μg/m³	358	4058		102	18 315
Avg Worker Pb Exposure, μg/m³	3500	10 690	15 455	8652	9227
Inside Hood, μg/m³			<4.3		16
PM_{10} Upwind Particulate, μg/m³	NT	130	152	NT	NT
PM_{10} Downwind Particulate, μg/m³	NT	124	39	NT	NT
PM_{10} Upwind Pb, μg/m³	1.7	NT	BDL[3]	16.7	BDL
PM_{10} Downwind Pb, μg/m³	2.3	NT	BDL	6.2	BDL
TSP Upwind Pb, μg/m³	0.6	2.2	BDL	BDL	BDL
TSP Downwind Pb, μg/m³	13.9	8.5	BDL	8.5	BDL
Surface Area Cleaned, m²/h (ft²/h)	2.88 (31)	5.48 (59)	6.04 (65)	5.3 (57)	6.32 (68)

[1] Perp = Perpendicular.

[2] NT = Not Tested.

[3] Below Detectable Limits.

Average area cleaned = 5.2 m²/h (62.5 ft²/h). If the normal production-factor increases for nozzle size are applied to this average production rate, the result would not be significantly different from the results obtained in the tests using steel grit abrasive.
Average worker lead exposure = 11 006 μg/m³.

TEST 3: VACUUM BLASTING

EQUIPMENT:

Vacuum Blast Equipment	An LTC, Inc. unit employing three different blasting heads designed for flat surfaces, outside edges, and corners.
Air Compressor	21 m^3/min (750 CFM)
Blast Hose	15 m (50 ft)
Blast Pressure	7 kgf/cm^2 (100 lbf/in^2) of pressure at the nozzle.
Blasting Nozzle	6.35-mm (1/4-in) nozzle supplied on unit; size matched to vacuum capacity.

Two trials were performed—one with an aluminum oxide abrasive and one with a steel grit abrasive.

All equipment was operated within normal parameters. The machine was set up by personnel familiar with its operation. The blaster had relatively easy access to all surfaces.

Containment was not used.

All surfaces were blasted to an SSPC-PC10, Near-White condition.

Due to low filter loading, the personal air sampling filters were not changed every hour.

Table 66. Vacuum blasting.

	Test 1	Test 2
Test Date	7-15-93	7-16-93
Test Duration in hours	2.5	2.5
Wind, km/h (mi/h)	8.05 (5)	16.1 (10)
Avg Worker Pb Exposure, $\mu g/m^3$	26	8.1
PM_{10} Upwind Pb, $\mu g/m^3$	BDL[1]	BDL
PM_{10} Downwind Pb, $\mu g/m^3$	BDL	BDL
TSP Upwind Pb, $\mu g/m^3$	BDL	BDL
TSP Downwind Pb, $\mu g/m^3$	BDL	BDL
Surface Area Cleaned, m^2/h (ft^2/h)	1.3 (14)	1.34 (14.4)

[1] Below Detectable Limits.

Average surface area cleaned = 1.32 m^2/h (14.2 ft^2/h). Average worker lead exposure = 17 $\mu g/m^3$.

TEST 4: POWER TOOLS

EQUIPMENT:

Power Tools	Two sets were used: Test 1—Air rotopeen, air needle gun, and air 90-degree grinder using soft grit-impregnated disk. Test 2—Electric rotopeen, air needle gun and electric 90-degree grinder using soft grit-impregnated disk. All tools were equipped with vacuum equipment typically found in the power tool cleaning industry.

All equipment was operated within normal parameters. The machine was set up by personnel familiar with its operation. The operator had relatively easy access to all surfaces.

All surfaces were cleaned to SSPC-SP11, the equivalent of a Near-White condition.

Both tests used ventilated containments with an airflow of 7.62 m/min (25 ft/min) on the average. Two fans rated at 283 m^3/min (10,000 CFM) each were equipped with dust socks to achieve the ventilation. Containment size was 4.27 m tall, 2.44 m wide, and 15 m long (14 ft tall, 8 ft wide, and 50 ft long).

Due to low filter loading, the personal air sampling filters were not changed every hour.

All air monitors were located 15 m (50 ft) downwind. Upwind monitors were not used.

Table 67. Power-tool cleaning.

	Test 1	Test 2
Test Date	5-14-93	5-10-93
Test Duration, hours	3	3
Containment Height	4.27 m (14 ft)	4.27 m (14 ft)
Orientation to Beams	Perp[1]	Perp
Wind, km/h (mi/h)	24.14 (15)	8.05 (5)
Avg Worker Pb Exposure, $\mu g/m^3$	95 [2]	118
PM_{10} Downwind Pb, $\mu g/m^3$	BDL[3]	BDL
TSP Downwind Pb, $\mu g/m^3$	BDL	BDL
Surface Area Cleaned, m^2/h (ft^2/h)	1.02 (11)	0.28 (3)

[1] Perp = Perpendicular.

[2] Due to arm fatigue, two operators were used; therefore, the personal air sampling device was attached to the second worker when they switched.

[3] Below Detectable Limits.

Average area cleaned = 1.0 m^2/h (11 ft^2/h). The electric tools were deemed unsuitable due to difficulty of use, low productivity, and overheating problems encountered with the electric motor. Average worker lead exposure = 106 $\mu g/m^3$.

In addition to the above information, all the paint chips that were collected into the vacuum system and those that fell onto a rubber blanket below the cleaning operation were weighed. Obviously lead that became airborne during the operation was not included.

1675 g of paint were collected in the vacuum system (73 percent of total).

606 g were collected from the ground cover (27 percent of total).

TEST 5: CHEMICAL STRIPPING

EQUIPMENT:

Conventional internal mix spray equipment for application of the stripper

Two pressure washers were used:

A standard airless system using a 30:1 pump @ 7 kgf/cm^2 (100 lbf/in^2) or 211 kgf/cm^2 (3,000 lbf/in^2) of pressure at the gun.

A recycling system that vacuumed the water as it was being used (similar in concept to a vacuum blaster).

All equipment was operated within normal parameters. The process was set up and operated by personnel trained in the use and application of chemical strippers. Personnel had relatively easy access to all surfaces.

The time for each trial was variable, depending on weather conditions. The chemical stripper must be allowed to dry before removing. Drying is dependent on weather conditions. All test applications conducted at the site were allowed to dry overnight. All tests conducted at the site utilized a dual-application technique for the stripper prior to the removal of the paint.

All surfaces were cleaned to be relatively free of lead. Spots of lead primer—small, but easily visible by the unaided eye—remained on the surface. The appearance was similar to the small traces of primer left with both vacuum blasting and power tool cleaning.

Containment was used; ventilation was not used. The containment was constructed so that no water could escape. All water was collected. Since other lead work had been performed in the same area, background lead monitoring was performed to ascertain that any lead present was generated by the chemical stripping operation and was not contamination from a lead-containing environment. Background lead measurements using 2-L pumps both produced results below 5 μg/m^3.

The operator did considerable experimentation the first day; therefore, the production rates may be misleading. The second day went very smoothly. The production rates obtained appeared routinely achievable. It is anticipated that it will be possible to achieve somewhat higher rates during regular operations.

Personal air samplers were not changed. Prior to the test, the equipment operators had stated that respirators were not necessary. However, monitoring results indicate that respirators should have been used. Monitoring was done without regard to the cleaning tool used. Only one set of filters was used for both the high-pressure rinsing and the recycling tool. Observation of the process clearly indicated that lead exposure to the workers occurred mainly during the high-pressure rinsing. For this reason, the entire rinsing operation is reported as high-pressure rinsing. If high-pressure rinsing equipment had been used exclusively, the exposure probably would have been slightly higher.

Environmental monitors were used the first day. Once the operation was observed for that day, and since the containment was inside a large contained area, it was apparent the operation would not result in lead releases greater than the detection limits of the monitors.

Table 68. Chemical stripping.

	Test 1	Test 2	Test 3	Test 4
Test Date	6-30-93	6-30-93	7-1-93	7-1-93
Test Duration in hours	1.1	0.5	0.33	0.42
Containment Height	2.13 m (7 ft)	2.13 m (7 ft)	2.13 m (7 ft)	2.13 m (7 ft)
Orientation to Beams	Parallel	Parallel	Parallel	Parallel
Wind, km/h (mi/h)	0 (0)[1]	0 (0)	0 (0)	0 (0)
Worker One[2] Pb Exposure, $\mu g/m^3$	NT[3]	123	NT	500
Worker Two[2] Pb Exposure, $\mu g/m^3$	NT	194	NT	350
PM_{10} Downwind Pb, $\mu g/m^3$	BDL[4]	BDL	NT	NT
TSP Downwind Pb, $\mu g/m^3$	BDL	BDL	NT	NT
Surface Area Cleaned, m^2/h (ft^2/h)	2.6 (28)	7.43 (80)	5.76 (62)	8.83 (95)

[1] The containment was set up inside a larger containment. This is the reason there was no wind.

[2] Worker One operated the rinsing equipment. Worker Two operated the vacuum equipment. On the second day, a monitor was also used as an area monitor inside containment. This monitor measured 357 $\mu g/m^3$ of lead in the contained area.

[3] NT = Not Tested. Since the containment was inside a larger contained area, there was no chance of a problem with environmental exposure.

[4] BDL = Below Detectable Limits.

APPENDIX D: FIELD EVALUATIONS

Three separate projects were visited in 1990 and 1991 for a detailed review and monitoring in accordance with the work plan. The monitoring study was unsuccessful for a wide variety of reasons—the most important of which was lack of control over variables. It became apparent very early that in order to assess even a limited number of variables, such as environmental releases, worker exposure, containment effectiveness, and ventilation requirements, many sites should be documented. Because there was not enough time or funds to do a proper study using field structures, it was decided to rework the study to include a test structure where all variables could be controlled.

The information collected at these sites was still valuable. Therefore, the following briefly describes what was done and the data that were collected.

In 1990 and early 1991, it was thought that PM_{10} monitoring was the method of the future and that it would replace TSP monitoring for measuring lead in the air. Therefore, only PM_{10} monitors were used to measure both particulates and lead.

PROJECT #1

DESCRIPTION:

- Large multi-span, multi-girder structure.
- Five spans contained at once; simple hanging tarps.
- Containment average size (21 m wide by 91 m long by 5.5 m high (70 ft wide by 300 ft long by 18 ft high)).
- Air forced in one end and exhausted out the other.
- 2125-cmm (75,000-CFM) (rated capacity—not measured) dust collectors were used.
- PM_{10} monitors placed around the containment as follows:
  - Monitor 1—38 m (125 ft) from the input air end of containment.
  - Monitor 2—19 m (61 ft) from the side of containment, approximately in the middle of the contained area.
  - Monitor 3—27 m (90 ft) from the side of containment (opposite Monitor 2) across from the air exhaust ducts exiting containment.
  - Monitor 4—30 m (100 ft) from the side of containment (opposite Monitor 2) and 11 m (37 ft) from input air.

The data collected on job conditions and air monitoring are reported in table 69.

Table 69. Air-monitoring results for Project #1.

	Winds	Weather	PM_{10} ($\mu g/m^3$)	Respirable Lead $\mu g/m^3$	Daily Production Rate m^2 (ft^2)	No. of Blasters	Hours Blasted	Hours Monitored
Day 1	Very Light	P.C.			381 (4100)	5	7.25	8.5
Monitor 1			1513	1.7				
Monitor 2			217	17.4				
Monitor 3			58	3.5				
Monitor 4			354	1.5				
Day 2	Very Light	P.C.			357 (3844)	4	6.25	8
Monitor 1			271	0.3				
Monitor 2			62	2.9				
Monitor 3			330	17.9				
Monitor 4			30	1				

WORKER EXPOSURE

Worker exposure monitoring was conducted using standard techniques in compliance with NIOSH Method No. 7105. Personal air monitors were placed on workers. Other monitors were placed at various locations around the project site. The results obtained are reported in tables 70 and 71.

Table 70. Lead concentrations from personal breathing zone sampling for Project #1.

Date	Job Class	Filter #	Work Area	Sample Time, min	Lead, µg/m³
2-26	Laborer	1	Out	275	106
		2	Out	200	40
2-26	Pot Tender	1	Out/In	159	5913
		2	Out/In	114	2640
		3	Out/In	208	2053
2-26	Blank	1			
		2			
2-27	Blaster	1	In	96	37 344
		2	In	179	55 475
2-27	Blaster in Hood	1	In	63	1363
		2	In	170	962
2-28	Pot Tender	1	In/Out	256	5710
		2	In/Out	131	183
2-28	Laborer	1	Out	261	72
		2	Out	115	2770
2-28	Monitoring Personnel	1	Out	354	8

Table 71. Lead concentrations from area sampling for Project #1.

Date	Location	Filter #	Time (Min)	Lead, µg/m³
2-26	Gang Trailer	1	266	123
		2	190	5
2-26	Outside, West Side of Containment	1	84	674
2-26	Near Dust Collectors	1	77	2358
		2	114	388
2-27	18.3 m (60 ft) East of Containment	1	466	24
2-27	Near Dust Collectors	1	222	103
		2	130	14
2-27	Blank	1	--	1
		2	--	1
2-28	Near Dust Collectors	1	231	130

Wipe samples were taken on various surfaces around the project. Table 72 presents the lead concentrations obtained.

Table 72. Lead on surfaces from wipe samples for Project #1.

Date	Location	Lead, $\mu g/ft^2$
2-26	Blank	19
2-26	Below West Side of Containment	4731
2-26	Top of Dust Collector	40 210
2-26	Side of Gang Trailer	249
2-28	18.3 m (60 ft) East of Containment	647
2-28	Inside Gang Trailer	70 020

DISCUSSION

The project was generally typical of projects of the time. It is clear that to be in compliance with current regulations, there would need to be significant changes. At a minimum, the following would need to be improved:

- Containments would have to be better sealed.
- Respirators with higher protection factors should have been used.
- Better air movement is necessary in containment.
- Much better cleaning of jobsite trailers and eating areas is necessary.
- The lead area definition must be clear; i.e., where the action level is exceeded.

PROJECT #2

This project used steel abrasive blasting on an elevated structure. Containment enclosures were approximately 7.3 m (24 ft) wide, 29.3 m (96 ft) long, and 4.6 m (15 ft) tall. The floor was a grate that collected and transferred the spent abrasive to the ground through four tubes. Spent material was then air transferred to the steel recycling equipment. An 509.7-cmm (18,000-CFM) dust collector provided the ventilation in containment.

PM_{10} MONITORING

PM_{10} monitors were placed at various locations around the site. There was always one monitor upwind from the blasting operation, one approximately 15 m (50 ft) downwind from the recycling and abrasive equipment, and the other two were at the edge of the right-of-way. As can be seen from the data in table 73, the PM_{10} monitor downwind from the equipment collected significant amounts of lead. It would appear that since the visible dust blew over the monitors because of a mild wind, then most certainly not all of the fine particulates leaking from containment were captured by the PM_{10} monitors. Equipment emissions appear to be high enough to be of concern.

Table 73. PM_{10} monitoring results from Project #2.

	Winds mi/h	Weather	Particulates $\mu g/m^3$	Respirable Lead $\mu g/m^3$	Blasting Hours	Monitoring Hours
Day 1	5 - 10	Clear			3	8
Monitor 1			13	2.8		
Monitor 2			18	0.1		
Monitor 3^A			109	5.8		
Monitor 4			69	0.3		
Day 2	5 - 10	Clear			0	8
Monitor 1			155	1.2		
Monitor 2			139	0.3		
Monitor 3			184	0.6		
Monitor 4			142	2.5		
Day 3	10 - 15	Clear			7.5	8
Monitor 1			106	5.7		
Monitor 2^A			330	71.1		
Monitor 3			112	6.9		
Monitor 4			100	1.3		
Day 4	3 - 5	Clear			1.5	7.5
Monitor 1			73	0.2		
Monitor 2			44	0.6		
Monitor 3^A			59	8.5		
Monitor 4			68	6.7		
Day 5	3 - 5	Clear			5.5	8
Monitor 1			83	1.1		
Monitor 2			105	0.3		
Monitor 3			128	6.5		
Monitor 4^A			305	56.7		

^A 24 m (80 ft) Downwind.

PERSONAL LEAD MONITORING

Air monitoring was done on various personnel at the site in accordance with NIOSH Method 7105. Table 74 contains the results of this monitoring.

Table 74. Personal lead monitoring at Project #2.

Date	Job Class	Location	Filter #	Time, min	Lead, $\mu g/m^3$
3-5	Laborer	Containment Setup	1	449	137
3-6	Laborer	Containment Setup	1	491	24
3-6	Pot Tender	Ground Level	1	29	
3-6	Blank				8
3-6	Blank				8
3-7	Blaster	In Containment	1 2	240 110	27 940 185 440
3-7	Blaster In Hood	In Containment	1 2	240 110	23 130 856
3-7	Blank				6
3-7	Blank				2
3-8	Blaster In Hood	In Containment	1 2	255 149	198 149

AREA SAMPLES WITH 2-L PUMPS

Personnel monitors were located around the site. All but one of these recorded results below the action level for lead. Results are contained in table 75.

Table 75. Area sampling with personal monitors at Project #2.

Date	Location	Sample Time, min	Lead, $\mu g/m^3$
3-4	Near Dust Collector	485	3
3-4	Entrance to Decon Trailer	482	4
3-4	Decon Trailer Dirty Side	476	2
3-4	Decon Trailer Clean Side	475	2
3-4	Blank		2
3-4	Blank		2
3-5	Blast Equipment	459	4
3-5	Below Containments	455	7
3-5	Below Containments	454	2
3-5	15.2 m (50 ft) South of Decon Trailer	440	1
3-5	Blank		1
3-5	Blank		2
3-6	Near Dust Collector	482	15
3-6	15.2 m (50 ft) South of Containment	336	7
3-6	Tool Storage Area	482	2
3-8	15.2 m (50 ft) South of Containment	473	34
3-8	Grocery Store Loading Dock	476	4
3-8	Blank		1
3-8	Blank		1

LEAD IN SURFACE DUST

Ten samples were collected around the jobsite in accordance with HUD Guidelines for Lead-Based Paint, April 18, 1990, Appendix A-5.4. Results are in table 76.

Table 76. Lead concentration on surfaces at Project #2.

Date	Location	Results ($\mu g/m^3$)
3-5	Decon Trailer Dirty Side, Wall	438
3-5	Decon Trailer Dirty Side, Floor	20 295
3-5	Decon Trailer Clean Side, Wall	37
3-5	Decon Trailer Clean Side, Floor	7644
3-5	Blasting Equipment	680
3-5	Portable Man Lift	41 910
3-8	Concrete Below Containment	171 821
3-8	Concrete Store Loading Dock	89 620
3-8	Blank	51
3-8	Steps to Decon Trailer	4710

APPENDIX E. CONTAINMENT FABRICS

INTRODUCTION

There is a wide assortment of containment fabrics available for constructing containment. Each of the suppliers of these materials have numerous claims as to the suitability of use for containing lead during blasting operations. There is no specification for fabrics. The purpose of this research was to establish some guidelines as to the minimum specification requirements that would ensure that a State highway agency is obtaining sufficient containment for the duration of the job. In addition, it was anticipated that a determination could be made regarding minimum distances between the containment materials and the blasting operation. Tests were developed to evaluate the durability and permeability of the fabrics and the seams to lead dust.

DURABILITY

A chamber was made out of plywood that measured 1 by 1 by 2 m (3.28 by 3.28 by 6.56 ft). In the 1- by 1-m (3.28- by 3.28-ft) end, a blasting hose and #6 Venturi nozzle was affixed so that it would blast down the 2-m (6.56-ft) distance of the chamber. At 0.91 m (3 ft), 1.22 m (4 ft), and 1.52 m (5 ft), wood frames were placed to hold taut a 0.61- by 0.61-m (2- by 2-ft) piece of the fabric to be tested. At a point 0.46 m (1.5 ft) in front of the nozzle, a flip-down plate was mounted. The baffle was held in place until the blasting system achieved a uniform flow rate of both air and abrasive. Once a uniform flow rate was established, a retaining pin was withdrawn to release the plate allowing the containment fabric to be blasted. To facilitate the detection of a perforation, a light was mounted behind the fabric, a window was installed in the front of the cabinet, and a video camera was used to record the time to perforation defined as when a 2.5-cm (1-in) hole was formed. In addition, a large dust bag collection system was used so that the dust could be removed fast enough to allow the operator to see when a perforation occurred. A coal slag abrasive (25/50 Black Beauty supplied by Reed Minerals) was used. The blasting pressure was 6 kgf/cm^2 (85 lbf/in^2). The abrasive flow rate was 4540 g/min (10 lb/min). Results of these tests are reported in table 77.

MATERIALS

The purpose of the testing was to establish guidelines, not to compare various manufactured products; therefore, brand names are not used. Each fabric is described as completely as possible.

Polyscreen 1

A woven polypropylene opacity screen (85-percent opacity) weighing 230 g/m^2 (0.75 oz/ft^2). Air easily passed through the material.

Polyscreen 2

This is a 95-percent opacity screen weighting 200 g/m^2 (0.65 oz/ft^2). Air easily passed through the material.

Polyscreen 3

A woven polypropylene opacity screen (85-percent opacity) weighing 181 g/m^2 (0.59 oz/ft^2). Air easily passes through the material.

Polyscreen 4

This is a 95-percent opacity screen weighing 239 g/m^2 (0.78 oz/ft^2). Air easily passed through the material.

Woven PolyTarp

This material is a tightly woven polypropylene weighing 221g/m^2 (0.72 oz/ft^2). Air passed through the material.

Coated Woven PolyTarp

Same as the Woven PolyTarp with the addition of a thin film of polyethylene laminated to a surface. The weight of the material is 230 g/m^2 (0.75 oz/ft^2). The material was relatively impermeable to air.

Reinforced Polyethylene 1

Polyethylene sheeting laminated to either a polyester or polyethylene fiber reinforcement. The weight of the material is 307 g/m^2 (1 oz/ft^2). The material was impermeable to air.

Reinforced Polyethylene 2

Polyethylene sheeting laminated to either a polyester or polyethylene fiber reinforcement. The weight of the material is 307 g/m^2 (1 oz/ft^2). The material was impermeable to air.

Reinforced Polyethylene 3

Polyethylene sheeting laminated to either a polyester or polyethylene fiber reinforcement. The weight of the material is 276 g/m^2 (0.9 oz/ft^2). The material was impermeable to air.

Laminated Tarp

The same as Polyscreen 1 with a laminated vinyl layer. The weight of the material is 254 g/m^2 (0.83 oz/ft^2). The material was impermeable to air.

369-g (13-oz) Vinyl

A thick vinyl material that is reinforced with nylon or polyester cord. The weight of the material is 457 g/m^2 (1.5 oz/ft^2). The material is impermeable to air.

510-g (18-oz) Vinyl

A heavier version of the 369-g (13-oz) vinyl. The weight of the material is 610 g/m^2 (2.0 oz/ft^2). The material was impermeable to air.

Reinforced Rubber

This material is a rubber mat reinforced with nylon or polyester cord weighing 1290 g/m^2 (4.2 oz/ft^2). The material was impermeable to air.

Worn Coated Tarp
A coated woven PolyTarp that was exposed to the elements for 6 months. Air easily passed through the material.

RESULTS

Table 77. Fabric perforation time.

Material Tested	Time to Perforation, seconds		
	@ 0 .91 m (3 ft)	@ 1.22 m (4 ft)	@ 1.52 m (5 ft)
Reinforced Rubber	43	>150	Not tested
510-g (18-oz) Vinyl	4.7	17.7	116
369-g (13-oz) Vinyl	2.2	11.3	98
Laminated Tarp	1.2	3	19.1
Reinforced Polyethylene 1	1.7	5.1	17.5
Reinforced Polyethylene 2	2.2	5.2	16.7
Reinforced Polyethylene 3	1.5	3.9	14.1
Coated PolyTarp	1.2	3.7	12.7
PolyTarp	1.2	4	10.7
Polyscreen 1	0.8	2.9	11.9
Polyscreen 2	1.1	3	11.1
Polyscreen 3	1.1	3.3	7.5
Polyscreen 4	1.1	1.8	7.1

PERMEABILITY

TEST EQUIPMENT

A chamber was made of plywood and lumber that measured 2.44 by 2.44 by 7.32 m (8 by 8 by 24 ft). On the long sides of the chamber there were four 2.13-m^2 (49-ft^2) openings, two on each side. The materials to be tested were mounted over these four openings by securing a piece of lumber around the perimeter of the opening with screws. Even though these seals were very tight, some of the lead escaped from the chamber. A lead-containing spent abrasive was introduced into the box at one end using an abrasive blasting system with the pressure set to 59 762 kgf/m^2 (85 lbf/in^2) and an abrasive flow rate of 4.54 kg/min (10 lb/min). A 1.22-m by 1.22-m by 15.9-mm

(4-ft by 4-ft by 5/8-in) steel plate was mounted both directly in front of the nozzle and 460 mm (18 in) away. The spent abrasive left the nozzle and hit the steel plate. A 508-mm (20-in) high-speed fan was mounted directly below the plate. The purpose of the fan was to keep the lead particulate in suspension in the chamber. In the far end of the chamber, a large dust sock was mounted to prevent pressure buildup within the chamber while the lead dust was being introduced. The lead-containing abrasive was introduced at a rate of 4540 g/min (10 lb/min). Personal air monitors were used to measure the lead inside of the chamber and outside the chamber in the center of the mounted sample. The sampling time was 1 h. After each trial, the chamber was thoroughly vacuumed.

The lead-containing spent abrasive was obtained from a project that had used a mineral sand stabilized with steel grit as the abrasive. The spent abrasive had a total lead content of approximately 23,000 parts per million (ppm). Based on observations made at the project, and the fact that the lead-containing abrasive was blasted a second time against a steel surface, it was assumed that the particle size of the lead was very small. No tests were performed to determine the actual particle size.

TESTED MATERIALS

The same materials that were tested for durability were used to test permeability. The screens allowed so much dust to pass through that it was readily visible. The two screens with the smallest openings were tested and found to be so permeable that screens with larger openings were not tested. In addition to evaluating containment fabrics, various seaming methods and in-use conditions were also tested. Results are reported in table 78.

During many of the tests, two of the four openings in the test chamber were covered with a rubber membrane. If the filters measuring lead concentration outside of containment gave results that were higher than 100 μg/m^3, it was generally assumed that there was a leak. The leak was repaired and the tests rerun. In total, there were 28 tests run with the rubber tarps. The average of these tests was 64 μg/m^3. Based on the average obtained, it was concluded that the minimum detectable limit for the test is in the range of 75 μg/m^3.

CONCLUSIONS

Containment fabrics should be able to withstand a direct blast for 3 s at 1.2 m (4 ft).

The distance between containment fabrics and the blasting operation should be a minimum of 1.5 m (5 ft), preferably 1.8 m (6 ft), if at all possible.

Screens that allow airflow do not adequately keep the lead contained. (It should be noted that the added cost of a coated woven material or many solid materials is not significantly greater than the cost of screens.)

The best lead-proof seams are rolled and clamped; however, any of the seaming methods that produced test results with a value less than 100 μg/m^3 appear to be adequate.

TEST RESULTS

Table 78. Lead permeability of materials and seams.

Material Tested	Lead Concentration Inside Chamber, $\mu g/m^3$	Lead Concentration Outside Chamber, $\mu g/m^3$
Reinforced Rubber	20 250	<75
369-g (13-oz) Vinyl	25 000	<75
Reinforced Polyethylene 1	31 250	<75
Coated PolyTarp	55 625	<75
Polyscreen 1	Pump failure	3008
Polyscreen 2	17 000	2000
PolyTarp	24 791	825
Reinf. Poly 3 with rolled and clamped seams	22 500	<75
Coated PolyTarp with 0.3-m (1-ft) overlap lashed seam	48 167	100
Reinf. Poly 2 seamed with two-way tape and stretch ties	63 416	91
Reinf. Poly 3 with 0.3-m (1-ft) overlap with duct tape	61 667	82
369-g (13-oz) Vinyl with 50.8-mm-wide (2-in-wide) Velcro seam	25 583	1417
Worn Coated Tarp	19 583	345
Reinf. Poly 2 with 25.4-mm (1-in) tear	58 666	292
Reinf. Poly 2 with 25.4-mm (1-in) tear	62 250	266

Holes should be repaired as quickly as possible.

The effectiveness of coated woven products is reduced with usuage and at some age may not adequately restrict dust flow.

DISCUSSION

The test results suggested that screens should not be used for constructing containments. Even a worn tarp showed increased permeability compared to a new tarp of the same material. The data indicated that there were significant differences in the materials pertaining to permeability. It seems reasonable to conclude that only materials that adequately restrict particulate transfer should be used to construct containments.

APPENDIX F. VENTILATION TESTING

Ventilation is needed to control air emissions and to reduce worker exposure to lead. The OSHA Lead in Construction Industry Standard requires reducing worker exposure to the lowest level feasible (preferably to below the PEL), using engineering controls, prior to selection of adequate respiratory protection. The purpose of this study was to attempt to determine the optimum design of containment/ventilation systems that is practical on girder bridges and the factors that affect worker exposure levels to lead.

TEST BRIDGE

The bridge used in these tests had two 13.72-m (45-ft) spans with 3.05-m (10-ft) cantilevers over each pier. Ten 36WF160 beams on 2-m (6.5-ft) centers made up the bridge. Crossframes were all solid bent plates. Ground clearance was 3.2 m (10.5 ft). A solid (steel or wood) deck was used. The deck added a few inches, which resulted in an overall height of 4.27 m (14 ft) from the bottom of the deck to the ground. The bridge is a typical two-span freeway-grade separation and is further described in appendix C.

CONTAINMENTS

Four containment designs were evaluated. They are described as follows:

Perpendicular to the Beams and 2.13 m (7 ft) tall (Dance Floor)

This containment consisted of a plywood platform floor with a dimensional lumber frame that was suspended from the bridge beams using cables. Side walls were made from coated woven polypropylene tarps. Areas between steel members were sealed with tight-fitting plywood frames. This, in effect, made the fabric side walls only 1.22 m (4 ft) tall. The containment was built 2.44 m (8 ft) wide—a little narrower than a typical one-lane closure. All holes were sealed with urethane foam. One end of the containment was left open and various input air devices were evaluated. The other end was sealed with a sheet of plywood with two 508-mm (20-in) holes to which flexible ducting was attached. The cross-sectional area below the beams was 2.97 m^2 (32 ft^2) and 5.2 m^2 (56 ft^2) from the bottom of the deck. The length of the containment was 15.24 m (50 ft).

Perpendicular to the Beams and 4.27 m (14 ft) tall

The containment was similar to the above without the suspended plywood floor. Sidewall material was held close to the ground by pulling the material under taut cables at ground level. The air entry was kept in the same location. At the air-exit end, a plenum was made from plywood and the two 508-mm (20-in) ducts were affixed to the plenum.

Parallel With the Beams and 2.13 m (7 ft) tall (Dance Floor)

The same 2.13-m (7-ft) platform system described above was used and rotated 90 degrees so the long axis of the containment was parallel with the beams. The only difference was that a pier cap that interfered with airflow below the beams was located in the middle of the containment.

Parallel With the Beams and 4.27 m (14 ft) tall

This containment was constructed with the long axis parallel to the beams with sidewalls extending to the ground. The method of securing the tarps and end-wall construction was the same as described for the perpendicular containment.

AIR INPUT

Air velocity inside containment was measured with a hot-wire anemometer (Model #9850 manufactured by Alnor) in the following manner:

- The average of six equally spaced measurements in the 2.97-m^2 (32-ft^2) cross-sectional area just below the beams in a 2.13-m (7-ft) containment that was perpendicular to the beams.
- The average of nine equallyspaced measurements in the 4.65-m^2 (50-ft^2) cross-sectional area of the 2.13-m (7-ft) parallel containment.
- The average of 15 equally spaced measurements in the 6.13-m^2 (66-ft^2) cross-sectional area of the 4.27-m (14-ft) perpendicular containment.
- The average of 18 equally spaced measurements in the 7.8-m^2 (84-ft^2) cross-sectional area of the 4.27-m (14-ft) parallel containment.

Airflow was measured in cross-sectional areas at two locations: one 3.05 m (10 ft) from the input end and the other 3.05 m (10 ft) from the output end. Because the measurements close to the input end were highly variable due to eddy currents, only the measurements taken closer to the output end were used to determine the average flow through containment. Video recordings were also made of each test. In order to "see" air movement, smoke bombs were used. Airflow speeds could also be estimated by timing the movement of the smoke.

Airflows were also measured inside of the duct work from the containment to the dust collector. These measurements were taken in a 3.05-m (10-ft) section of smooth-wall, 508-mm (20-in) duct attached to the input ports on the dust collector. Measurements were taken about 1.83 m (6 ft) from the dust collector. This is somewhat closer than is recommended, but it was thought to be a workable method in the field. The measurement techniques that were used are outlined in the *Industrial Ventilation Manual of Recommended Practice, 20th Edition*, Section 9.3.1. The method consists of making a 20-point traverse in an "X" pattern with a pitot tube and manometer. (Model #400-10 manufactured by Dwyer or Model #530 manufactured by Alnor.) The dust collectors that were used had two 508-mm (20-in) ducts. Any exceptions to this are noted.

Five different air input methods were evaluated. These are:

Open Hole	This was a 1.22- by 2.44-m (4- by 8-ft) hole. This hole was approximately seven times larger than the air exit cross-sectional area.
Plywood Baffle	A baffle was made of staggered pieces of plywood affixed to each side of dimensional lumber and placed on the input end. Air input velocities of 305 to 457 m/min (1000 to 1500 ft/min) ½ horsepower were typical.

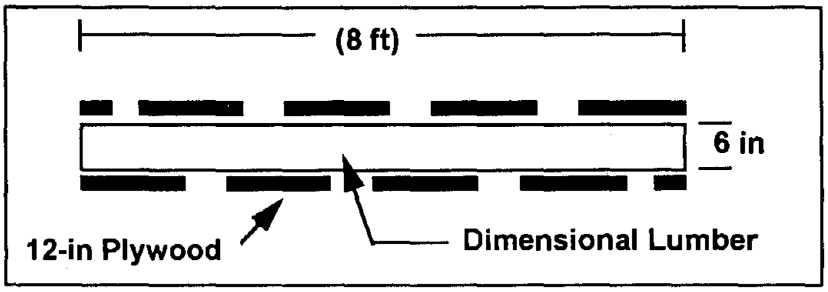

Figure 12. Top view of baffle. (1 ft = 0.305 m)

Low-Speed High-Volume Fan (LSHV)	The Dayton, ½ horsepower, 914-mm (36-in) fan had a rated delivery of 292 m^3/min (10,300 CFM) in free air. The air leaving the fan had a calculated speed of 444 m/min (1,457 ft/min). The air passing through the fan was higher due to the negative pressure on the output side of the fan.
High-Speed High-Volume Fan (HSHV)	This BlackMax 508-mm (20-in) fan had a rated delivery of 278 m^3/min (9,800 CFM) in free air. The air leaving the fan had a calculated speed of 1372 m/min (4,500 ft/min). The air passing through the fan was higher due to the negative pressure on the output side of the fan.
Nothing	No opening was made for input air.

Based on the testing described above, the following technique was used to measure airflows while conducting the blasting operations. Airflows were measured with a pitot tube using a 20-point traverse in the exit ducts. Airflow rates were calculated based on the quantity of air passing through the ducts and the cross-sectional area of the containment.

During the blasting tests, the following conditions were maintained:

- Air Velocity through Containment—The air velocity inside containment was a variable. Dust collectors were adjusted to obtain constant velocities.
- Air Input - Baffle—The air baffle is the easiest to set up and maintain. Generally, tests were designed to simulate workable alternatives. For this reason and due to limited time and funds, only one air input method could be thoroughly evaluated.
- Exit Air—Ducts were attached to plywood in the 2.13-m- (7-ft-) tall containments, and a designed exit plenum in the 4.27-m- (14-ft-) tall containments.

The data collected on measuring air velocity are presented on the following pages. The information on the top of each page indicates the containment type (design), air input type, operating parameters of the dust collector, and the measured negative pressure inside containment. Immediately below this general information are the individual data points obtained of air velocity in the ducts as measured with a pitot tube, with calculated average air velocity in the ducts, standard deviation, percent relative standard deviation, and volume of air moving through the ducts. On the lower part of each page are the individual data points obtained of air velocity inside containment as measured with a hot-wire anemometer, with calculated average air velocity inside containment, standard deviation, percent relative standard deviation, and volume of air moving through containment.

Table 79 presents the results of blasting tests.

Containment Type: Parallel to the Ground
Air Input Type: Open End
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 0.76 mm (0.03 in) of water

Air Velocity in Ducts, (ft/min)	3,402	3,221	2,927	3,575
	3,858	3,424	3,028	4,247
	4,247	3,678	3,102	4,421
	4,247	3,575	3,313	4,247
	4,067	3,358	3,799	4,247
	3,739	3,102	4,247	4,588
	3,596	2,953	4,067	4,067
	3,313	2,742	3,383	3,313
	3,221	2,658	3,267	3,244
	2,953	2,658	3,102	2,823
Average Velocity in Ducts, (ft/min)	3,525			
Standard Deviation of Velocity	534.7			
% Relative Standard Deviation	15.2			
Volume of Air through Ducts, (CFM)	15,369			

Air Velocity in Containment, (ft/min)	75	100	100
	200	300	400
	300	600	700
	600	600	400
	150	150	300
	200	200	100
Average Air Velocity in Containment, (ft/min)	304		
Standard Deviation of Air Velocity in Containment	202.2		
% Relative Standard Deviation	66.5		
Volume of Air through Containment, (CFM)	25,536		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Parallel to the Ground
Air Input Type:	High-Speed High-Volume Fan
Dust Collector:	509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	4.06 mm (0.16 in) of water

Air Velocity in Ducts, (ft/min)	3,424	3,424	3,174	3,759
	3,468	3,819	3,335	3,877
	3,575	4,067	3,380	3,819
	3,617	4,067	3,596	3,838
	3,596	3,699	4,247	3,779
	3,838	3,468	4,421	4,749
	4,247	3,596	4,421	4,421
	4,247	3,490	4,421	3,799
	4,067	3,335	3,877	3,575
	3,799	3,197	3,739	3,380
Average Velocity in Ducts, (ft/min)	3,791			
Standard Deviation of Velocity	381.8			
% Relative Standard Deviation	10.1			
Volume of Air through Ducts, (CFM)	16,529			

Air Velocity in Containment, (ft/min)	200	1,300	300
	100	1,000	1,200
	150	200	700
	100	-200	150
	300	200	200
Average Air Velocity in Containment, (ft/min)	393		
Standard Deviation of Air Velocity in Containment	442.7		
% Relative Standard Deviation	112.6		
Volume of Air through Containment, (CFM)	33,012		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Parallel to the Ground
Air Input Type:	Baffle
Dust Collector:	509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	3.81 mm (0.15 in) of water

Air Velocity in Ducts, (ft/min)	2,742	2,630	3,197	4,247
	3,174	3,028	3,637	4,421
	3,290	3,244	3,575	4,247
	3,313	3,313	3,799	4,067
	3,150	2,953	4,421	4,588
	3,877	2,359	4,588	4,421
	4,067	2,294	4,421	3,877
	4,247	2,193	4,421	3,244
	4,067	2,124	3,877	3,028
	4,247	1,939	3,313	3,028
Average Velocity in Ducts, (ft/min)	3,517			
Standard Deviation of Velocity	751.6			
% Relative Standard Deviation	21.4			
Volume of Air through Ducts, (CFM)	15,334			

Air Velocity in Containment, (ft/min)	200	250	275
	400	300	300
	500	500	500
	500	500	500
	500	525	550
	400	400	400
Average Air Velocity in Containment, (ft/min)	417		
Standard Deviation of Air Velocity in Containment	108.8		
% Relative Standard Deviation	26.1		
Volume of Air through Containment, (CFM)	35,028		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Parallel to the Ground
Air Input Type: Low-Speed High-Volume Fan
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 2.03 mm (0.08 in) of water

Air Velocity in Ducts, (ft/min)	2,927	2,658	2,902	3,532
	3,380	2,953	3,102	3,637
	3,511	3,102	3,174	3,468
	3,468	3,221	3,244	3,554
	3,380	3,078	4,067	3,739
	3,877	2,742	4,421	4,421
	4,247	2,902	4,247	4,247
	4,247	2,953	4,421	3,819
	4,067	2,823	4,421	3,490
	3,637	2,452	4,247	3,244
Average Velocity in Ducts, (ft/min)	3,526			
Standard Deviation of Velocity	565.4			
% Relative Standard Deviation	16			
Volume of Air through Ducts, (CFM)	15,373			

Air Velocity in Containment, (ft/min)	100	150	200
	300	300	350
	400	400	300
	400	500	400
	500	450	450
	400	350	350
Average Air Velocity in Containment, (ft/min)	350		
Standard Deviation of Air Velocity in Containment	111.1		
% Relative Standard Deviation	31.7		
Volume of Air through Containment, (CFM)	29,400		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Input Type: Closed
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 7.37 mm (0.29 in) of water

Air Velocity in Ducts, (ft/min)	2,842	3,470	3,318	3,832
	3,340	3,812	3,675	4,197
	3,675	4,197	4,019	4,197
	3,832	4,533	4,197	4,197
	4,369	4,019	3,774	3,832
	4,996	4,847	3,089	2,943
	4,996	4,996	2,736	2,943
	4,847	5,140	2,736	3,017
	4,693	4,847	2,709	3,089
	4,197	4,533	2,362	3,089
Average Velocity in Ducts, (ft/min)	3,853			
Standard Deviation of Velocity	770			
% Relative Standard Deviation	20			
Volume of Air through Ducts, (CFM)	16,799			

Air Velocity in Containment, (ft/min)	400	150	200
	450	250	250
	400	400	300
	300	300	300
	200	300	300
Average Air Velocity in Containment, (ft/min)	300		
Standard Deviation of Air Velocity in Containment	84.5		
% Relative Standard Deviation	28.2		
Volume of Air through Containment, (CFM)	19,800		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Closed
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 7.62 mm (0.30 in) of water

Air Velocity in Ducts, (ft/min)	3,330	4,897	3,121	4,742
	3,330	4,742	3,193	5,048
	3,073	4,897	3,397	5,194
	3,048	5,048	3,330	4,897
	3,397	4,897	3,375	4,742
	5,048	4,897	4,897	4,581
	5,048	4,897	5,194	4,241
	4,897	4,581	5,048	4,060
	4,581	4,581	4,897	3,872
	4,581	4,581	4,742	3,652
Average Velocity in Ducts, (ft/min)	4,364			
Standard Deviation of Velocity	722.4			
% Relative Standard Deviation	16.6			
Volume of Air through Ducts, (CFM)	19,027			

Air Velocity in Containment, (ft/min)	100	100	75
	400	300	300
	400	400	300
	300	300	300
	200	300	300
Average Air Velocity in Containment, (ft/min)	272		
Standard Deviation of Air Velocity in Containment	106.4		
% Relative Standard Deviation	39.1		
Volume of Air through Containment, (CFM)	17,952		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Closed
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 1,800 RPM
Negative Pressure Obtained: 7.11 mm (0.28 in) of water

Air Velocity in Ducts, (ft/min)	3,145	3,872	2,597	4,414
	3,145	4,060	2,682	4,581
	3,048	4,241	2,738	4,742
	2,871	4,241	2,792	4,241
	3,073	4,414	3,073	4,241
	5,048	4,581	4,581	4,241
	4,897	4,414	4,742	4,060
	4,414	4,241	4,581	3,793
	4,060	4,241	4,414	3,632
	3,793	4,060	3,872	3,506
Average Velocity in Ducts, (ft/min)	3,935			
Standard Deviation of Velocity	680.8			
% Relative Standard Deviation	17.3			
Volume of Air through Ducts, (CFM)	17,156			

Air Velocity in Containment, (ft/min)	400	300	75
	400	300	200
	400	300	250
	400	300	250
	175	250	250
Average Air Velocity in Containment, (ft/min)	283		
Standard Deviation of Air Velocity in Containment	93.4		
% Relative Standard Deviation	33		
Volume of Air through Containment, (CFM)	18,678		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: High-Speed High-Volume Fan
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 2.54 mm (0.1 in) of water

Air Velocity in Ducts, (ft/min)	3,105	3,033	2,496	3,358
	3,291	3,129	2,804	3,852
	3,509	3,402	3,402	4,392
	3,551	3,754	3,715	4,558
	3,852	4,220	3,530	4,220
	5,022	4,718	3,572	3,223
	5,168	5,022	3,735	3,105
	4,872	4,872	3,852	3,129
	4,558	4,558	3,813	3,223
	3,852	3,852	3,530	3,153
Average Velocity in Ducts, (ft/min)	3,800			
Standard Deviation of Velocity	675.6			
% Relative Standard Deviation	17.8			
Volume of Air through Ducts, (CFM)	16,568			

Air Velocity in Containment, (ft/min)	1,000	800	300
	400	2,000	1,100
	800	600	600
	300	150	250
	200	300	250
Average Air Velocity in Containment, (ft/min)	603		
Standard Deviation of Air Velocity in Containment	490.4		
% Relative Standard Deviation	81.3		
Volume of Air through Containment, (CFM)	39,798		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Baffle
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 3.05 mm (0.12 in) of water

Air Velocity in Ducts, (ft/min)	2,923	4,060	2,792	4,241
	2,923	4,241	2,845	4,414
	2,710	4,414	3,024	4,414
	2,509	4,414	2,509	4,414
	2,738	4,581	2,948	4,241
	4,742	4,742	4,414	4,060
	4,414	4,414	4,241	3,713
	4,414	4,241	4,241	3,527
	3,713	4,241	4,241	3,330
	3,833	4,060	3,590	2,974
Average Velocity in Ducts, (ft/min)	3,813			
Standard Deviation of Velocity	698.2			
% Relative Standard Deviation	18.3			
Volume of Air through Ducts, (CFM)	16,624			

Air Velocity in Containment, (ft/min)	300	225	150
	400	375	300
	325	350	350
	350	350	350
	250	300	350
Average Air Velocity in Containment, (ft/min)	315		
Standard Deviation of Air Velocity in Containment	64.6		
% Relative Standard Deviation	20.6		
Volume of Air through Containment, (CFM)	20,790		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Baffle
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 3.3 mm (0.13 in) of water

Air Velocity in Ducts, (ft/min)	3,391	4,544	3,435	2,715
	3,743	4,703	3,743	3,048
	3,840	4,857	4,027	3,190
	4,027	4,857	3,840	3,281
	4,027	4,703	4,027	4,027
	4,703	3,840	4,544	4,703
	4,857	3,540	4,544	4,703
	4,857	3,120	4,703	4,703
	4,207	3,167	4,544	4,703
	4,207	3,190	4,207	4,544
Average Velocity in Ducts, (ft/min)	4,090			
Standard Deviation of Velocity	623			
% Relative Standard Deviation	15.2			
Volume of Air through Ducts, (CFM)	17,832			

Air Velocity in Containment, (ft/min)	300	200	200
	300	350	300
	400	350	300
	350	300	400
	300	350	350
Average Air Velocity in Containment, (ft/min)	317		
Standard Deviation of Air Velocity in Containment	58.8		
% Relative Standard Deviation	18.5		
Volume of Air through Containment, (CFM)	20,922		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Baffle
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 3.3 mm (0.13 in) of water

Air Velocity in Ducts, (ft/min)	3,228	4,369	2,736	4,369
	3,247	4,533	2,763	4,369
	3,017	4,533	2,842	4,197
	2,816	4,369	2,842	4,019
	3,041	4,369	3,228	4,369
	4,996	4,847	4,533	4,197
	4,847	4,693	4,369	3,832
	4,533	4,533	4,369	3,532
	4,369	4,533	4,197	3,427
	4,197	4,197	4,197	3,136
Average Velocity in Ducts, (ft/min)	3,970			
Standard Deviation of Velocity	683.4			
% Relative Standard Deviation	17.2			
Volume of Air through Ducts, (CFM)	17,309.2			

Air Velocity in Containment, (ft/min)	350	300	350
	350	300	225
	400	350	400
	350	350	350
	150	250	300
Average Air Velocity in Containment, (ft/min)	318		
Standard Deviation of Air Velocity in Containment	67.1		
% Relative Standard Deviation	21.1		
Volume of Air through Containment, (CFM)	20,988		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Baffle with Ducts on the Ground into Containment
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 3.81 mm (0.15 in) of water

Air Velocity in Ducts, (ft/min)	3,330	4,581	3,713	5,475
	3,548	4,742	3,852	5,337
	3,611	4,742	3,872	5,337
	3,734	4,742	3,852	5,337
	3,872	4,414	4,241	5,610
	4,581	3,353	4,581	5,871
	4,581	2,738	4,742	5,742
	4,241	2,323	4,742	5,610
	4,241	2,323	4,742	5,742
	4,241	2,568	4,241	5,610
Average Velocity in Ducts, (ft/min)	4,369			
Standard Deviation of Velocity	951.1			
% Relative Standard Deviation	21.8			
Volume of Air through Ducts, (CFM)	19,048			

Air Velocity in Containment, (ft/min)	300	200	50
	350	200	150
	300	200	200
	450	300	300
	400	350	450
Average Air Velocity in Containment, (ft/min)	280		
Standard Deviation of Air Velocity in Containment	113.1		
% Relative Standard Deviation	40.4		
Voume of Air through Containment, (CFM)	18,480		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Low-Speed High-Volume Fan
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 6.35 mm (0.025 in) of water

Air Velocity in Ducts, (ft/min)	3,380	2,778	2,857	3,572
	3,509	2,882	3,008	4,220
	3,735	3,057	3,530	4,392
	4,220	3,314	3,774	4,220
	4,872	3,852	3,467	3,176
	5,168	4,392	3,509	3,129
	4,872	4,872	3,852	3,153
	4,392	4,718	4,040	3,268
	4,040	4,558	4,220	3,488
	3,654	4,392	3,794	3,488
Average Velocity in Ducts, (ft/min)	3,820			
Standard Deviation of Velocity	630.1			
% Relative Standard Deviation	16.5			
Volume of Air through Ducts, (CFM)	16,655			

Air Velocity in Containment, (ft/min)	350	400	400
	400	450	500
	400	400	450
	350	400	400
	300	300	250
Average Air Velocity in Containment, (ft/min)	383		
Standard Deviation of Air Velocity in Containment	64.5		
% Relative Standard Deviation	16.8		
Volume of Air through Containment, (CFM)	25,278		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Perpendicular to the Ground
Air Input Type:	Low-Speed High-Volume Fan
Dust Collector:	566.34 m³/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	0.76 mm (0.03 in) of water

Air Velocity in Ducts, (ft/min)	3,097	5,194	3,330	3,239
	3,833	5,194	3,548	3,239
	3,872	5,194	3,773	3,239
	3,872	5,194	3,773	3,239
	4,060	4,742	3,852	3,632
	4,581	3,872	4,414	4,581
	4,742	3,506	4,414	4,581
	4,897	3,216	4,581	4,414
	4,414	3,073	4,241	4,414
	4,414	3,073	3,872	4,241
Average Velocity in Ducts, (ft/min)	4,066			
Standard Deviation of Velocity	653.3			
% Relative Standard Deviation	16.1			
Volume of Air through Ducts, (CFM)	17,728			

Air Velocity in Containment, (ft/min)	300	200	150
	300	250	300
	350	350	400
	350	350	375
	450	400	375
Average Air Velocity in Containment, (ft/min)	327		
Standard Deviation of Air Velocity in Containment	79.3		
% Relative Standard Deviation	24.3		
Volume of Air through Containment, (CFM)	21,582		

1 ft/min = 0.3 m/min
1 CFM (ft³/min) = 0.028 CMM (m³/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Low-Speed High-Volume Fan
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 1800 RPM
Negative Pressure Obtained: 1.02 mm (0.04 in) of water

Air Velocity in Ducts, (ft/min)	3,375	3,872	2,738	4,241
	3,308	4,060	2,738	3,872
	2,974	4,060	2,710	4,060
	2,765	3,833	2,449	4,241
	2,948	3,611	2,897	4,060
	5,048	4,414	4,414	3,872
	4,581	4,414	4,581	3,773
	4,241	4,241	4,414	3,590
	4,060	4,060	4,241	3,353
	4,241	4,241	3,872	3,216
Average Velocity in Ducts, (ft/min)	3,792			
Standard Deviation of Velocity	634.1			
% Relative Standard Deviation	16.7			
Volume of Air through Ducts, (CFM)	16,533			

Air Velocity in Containment, (ft/min)	300	300	300
	400	350	350
	350	350	350
	350	375	350
	325	300	250
Average Air Velocity in Containment, (ft/min)	333		
Standard Deviation of Air Velocity in Containment	37.4		
% Relative Standard Deviation	11.2		
Volume of Air through Containment, (CFM)	21,978		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Perpendicular to the Ground
Air Input Type:	Open
Dust Collector:	566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	1.14 mm (0.045 in) of water

Air Velocity in Ducts, (ft/min)	3,441	4,742	3,121	4,060
	3,463	4,742	3,193	4,581
	3,169	4,897	2,999	4,897
	2,948	4,742	2,845	4,581
	3,419	4,241	3,506	4,581
	5,194	4,742	4,897	4,581
	5,194	4,742	4,897	4,060
	4,897	4,742	4,742	3,872
	4,581	4,742	4,742	3,713
	4,581	4,581	4,581	3,527
Average Velocity in Ducts, (ft/min)	4,244			
Standard Deviation of Velocity	703			
% Relative Standard Deviation	16.6			
Volume of Air through Ducts, (CFM)	18,503			

Air Velocity in Containment, (ft/min)	400	300	300
	350	250	300
	350	350	350
	300	350	350
	350	350	250
Average Air Velocity in Containment, (ft/min)	327		
Standard Deviation of Air Velocity in Containment	41.7		
% Relative Standard Deviation	12.8		
Volume of Air through Containment, (CFM)	21,582		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Open with Ducts on the Ground into Containment
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 1.02 mm (0.04 in) of water

Air Velocity in Ducts, (ft/min)	3,419	4,581	3,463	2,738
	3,773	4,742	3,773	3,073
	3,872	4,897	4,060	3,216
	4,060	4,897	3,872	3,308
	4,060	4,742	4,060	4,060
	4,742	2,872	4,581	4,742
	4,897	3,569	4,581	4,742
	4,897	3,145	4,742	4,742
	4,241	3,193	4,581	4,742
	4,241	3,216	4,241	4,581
Average Velocity in Ducts, (ft/min)	4,099			
Standard Deviation of Velocity	658			
% Relative Standard Deviation	16.1			
Volume of Air through Ducts, (CFM)	17,872			

Air Velocity in Containment, (ft/min)	300	200	200
	350	300	200
	400	300	400
	500	400	400
	500	450	450
Average Air Velocity in Containment, (ft/min)	357		
Standard Deviation of Air Velocity in Containment	103.3		
% Relative Standard Deviation	28.9		
Volume of Air through Containment, (CFM)	23,562		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Open
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 0.76 mm (0.03 in) of water

Air Velocity in Ducts, (ft/min)	3,623	2,398	3,498	4,207
	3,743	2,742	3,743	4,378
	4,027	3,391	4,027	4,544
	4,207	3,762	4,207	4,544
	4,857	3,840	4,027	4,378
	5,293	4,703	3,840	3,167
	5,007	4,703	4,207	3,190
	4,544	4,544	4,207	3,120
	3,840	4,207	4,207	3,391
	3,840	4,378	3,801	3,167
Average Velocity in Ducts, (ft/min)	3,987			
Standard Deviation of Velocity	615			
% Relative Standard Deviation	15.4			
Volume of Air through Ducts, (CFM)	17,383			

Air Velocity in Containment, (ft/min)	400	400	450
	350	300	400
	400	350	300
	300	300	350
	200	300	300
Average Air Velocity in Containment, (ft/min)	340		
Standard Deviation of Air Velocity in Containment	63.2		
% Relative Standard Deviation	18.6		
Volume of Air through Containment, (CFM)	22,440		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Dance Floor
Air Input Type: Open
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 1.52 mm (0.06 in) of water

Air Velocity in Ducts, (ft/min)	3,320	3,111	3,859	3,742
	4,047	3,859	4,566	3,859
	4,047	4,227	4,881	4,400
	4,400	4,400	4,881	4,566
	4,400	4,566	4,881	4,047
	4,726	4,881	5,032	3,742
	4,047	4,881	4,566	3,537
	3,859	4,881	4,227	3,297
	3,859	4,566	3,859	3,111
	3,661	4,047	10,498	1,930
Average Velocity in Ducts, (ft/min)	4,282			
Standard Deviation of Velocity	1,188			
% Relative Standard Deviation	27.7			
Volume of Air through Ducts, (CFM)	18,669			

Air Velocity in Containment, (ft/min)	750	900	250
	800	600	500
Average Air Velocity in Containment, (ft/min)	633		
Standard Deviation of Air Velocity in Containment	235.9		
% Relative Standard Deviation	37.3		
Volume of Air through Containment, (CFM)	20,256		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Dance Floor
Air Input Type: High-Speed High-Volume Fans
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 10.16 mm (0.4 in) of water

Air Velocity in Ducts, (ft/min)	4,052	4,886	4,232	4,232
	4,731	5,037	4,571	4,405
	4,731	5,183	4,731	4,886
	4,886	5,183	4,886	5,037
	4,886	5,037	4,886	5,183
	4,052	5,037	5,037	5,325
	4,052	5,037	4,232	4,886
	3,824	4,886	4,232	4,731
	4,052	4,731	3,765	4,232
	3,498	4,052	3,477	3,665
Average Velocity in Ducts, (ft/min)	4,562			
Standard Deviation of Velocity	512.4			
% Relative Standard Deviation	11.2			
Volume of Air through Ducts, (CFM)	19,890			

Air Velocity in Containment, (ft/min)	1,000	2,000	200
	500	1,800	500
Average Air Velocity in Containment, (ft/min)	1,000		
Standard Deviation of Air Velocity in Containment	745.7		
% Relative Standard Deviation	74.6		
Volume of Air through Containment, (CFM)	32,000		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Perpendicular to the Dance Floor
Air Input Type:	Baffle
Dust Collector:	566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	7.37 mm (0.29 in) of water

Air Velocity in Ducts, (ft/min)	4,052	4,232	3,765	4,571
	4,731	4,731	4,232	5,037
	4,886	4,886	4,571	5,183
	4,886	4,886	4,405	5,037
	5,037	5,325	4,571	5,183
	4,405	5,463	4,571	4,886
	4,052	5,325	4,052	4,232
	4,052	5,463	3,434	4,052
	3,844	4,886	3,232	3,705
	3,066	4,731	2,865	33,455
Average Velocity in Ducts, (ft/min)	4,522			
Standard Deviation of Velocity	764			
% Relative Standard Deviation	16.9			
Volume of Air through Ducts, (CFM)	19,716			

Air Velocity in Containment, (ft/min)	600	600	200
	700	600	100
Average Air Velocity in Containment, (ft/min)	467		
Standard Deviation of Air Velocity in Containment	250.3		
% Relative Standard Deviation	53.6		
Volume of Air through Containment, (CFM)	14,944		

1 ft/min = 0.3 m/min

1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular with a Dance Floor
Air Input Type: Baffle
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 6.86 mm (0.27 in) of water

Air Velocity in Ducts, (ft/min)	3,870	3,120	3,120	2,681
	4,239	3,461	3,306	2,870
	4,239	3,546	3,329	3,047
	4,239	3,732	3,373	3,144
	4,058	3,870	3,568	3,417
	3,870	3,546	4,239	4,239
	3,870	3,461	4,412	4,239
	4,058	3,525	4,239	4,239
	3,831	3,461	3,811	4,058
	3,191	3,191	3,417	3,417
Average Velocity in Ducts, (ft/min)	3,664			
Standard Deviation of Velocity	449			
% Relative Standard Deviation	12.3			
Volume of Air through Ducts, (CFM)	15,975			

Air Velocity in Containment, (ft/min)	500	500	500
	700	525	500
Average Air Velocity in Containment, (ft/min)	538		
Standard Deviation of Air Velocity in Containment	80.2		
% Relative Standard Deviation	14.9		
Volume of Air through Containment, (CFM)	17,216		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Perpendicular to the Dance Floor
Air Input Type:	Low-Speed High-Volume Fan
Dust Collector:	566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	4.83 mm (0.19 in) of water

Air Velocity in Ducts, (ft/min)	3,702	4,047	3,859	4,566
	4,400	4,726	4,566	4,726
	4,566	4,881	4,881	5,032
	4,566	5,032	4,726	5,178
	4,881	5,178	4,726	5,319
	4,881	5,319	4,881	4,566
	4,566	5,458	5,319	4,566
	4,047	5,178	4,726	4,566
	3,859	5,178	4,047	4,227
	3,342	4,566	4,047	1,726
Average Velocity in Ducts, (ft/min)	4,566			
Standard Deviation of Velocity	671.5			
% Relative Standard Deviation	14.7			
Volume of Air through Ducts, (CFM)	19,908			

Air Velocity in Containment, (ft/min)	900	1,300	600
	400	1,000	600
Average Air Velocity in Containment, (ft/min)	800		
Standard Deviation of Air Velocity in Containment	328.6		
% Relative Standard Deviation	41.1		
Volume of Air through Containment, (CFM)	25,600		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Dance Floor
Air Input Type: Low-Speed High-Volume Fan
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 2.79 mm (0.11 in) of water

Air Velocity in Ducts, (ft/min)	8,095	6,341		
	8,455	7,322		
	8,629	7,718		
	8,629	8,186		
	9,050	8,800		
	7,010	7,423		
	6,341	6,684		
	6,903	6,341		
	6,903	6,684		
	5,979	6,223		
Average Velocity in Ducts, (ft/min)	7,386			
Standard Deviation of Velocity	985			
% Relative Standard Deviation	13.3			
Volume of Air through Ducts, (CFM)	16,101			

Air Velocity in Containment, (ft/min)	800	500	300
	500	600	600
Average Air Velocity in Containment, (ft/min)	550		
Standard Deviation of Air Velocity in Containment	164.3		
% Relative Standard Deviation	29.9		
Volume of Air through Containment, (CFM)	17,600		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Parallel with a Dance Floor
Air Input Type: Open End
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: .25 mm (0.01 in) of water

Air Velocity in Ducts, (ft/min)	4,171	2,824	3,427	3,469
	4,341	2,849	3,552	3,632
	4,663	2,900	3,672	3,994
	4,505	2,746	3,672	4,171
	4,505	2,719	3,592	3,994
	3,363	3,531	3,552	3,298
	3,406	3,994	3,672	3,208
	3,186	4,663	3,731	3,093
	2,665	4,965	3,808	2,824
	3,298	5,109	3,672	2,772
Average Velocity in Ducts, (ft/min)	3,630			
Standard Deviation of Velocity	640			
% Relative Standard Deviation	17.6			
Volume of Air through Ducts, (CFM)	15,827			

Air Velocity in Containment, (ft/min)	290	170	90
	410	570	430
	800	600	600
Average Air Velocity in Containment, (ft/min)	440		
Standard Deviation of Air Velocity in Containment	228.2		
% Relative Standard Deviation	51.9		
Volume of Air through Containment, (CFM)	22,000		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Parallel with a Dance Floor
Air Input Type:	Baffle with Ducts on the Ground into Containment
Dust Collector:	509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained:	0 mm (0.0 in) of water

Air Velocity in Ducts, (ft/min)	7,097	4,646		
	7,395	4,946		
	7,587	5,089		
	7,297	4,946		
	5,497	4,488		
	4,646	4,946		
	5,626	6,233		
	6,570	7,097		
	6,891	7,587		
	5,497	8,311		
Average Velocity in Ducts, (ft/min)	6,120			
Standard Deviation of Velocity	1,215			
% Relative Standard Deviation	19.9			
Volume of Air through Ducts, (CFM)	13,219			

Air Velocity in Containment, (ft/min)	100	100	100
	450	500	500
	600	600	900
Average Air Velocity in Containment, (ft/min)	428		
Standard Deviation of Air Velocity in Containment	277.4		
% Relative Standard Deviation	64.8		
Volume of Air through Containment, (CFM)	21,400		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Parallel with Dance Floor
Air Input Type: Baffle
Dust Collector: 509.7 m^3/min (18,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 7.11 mm (0.28 in) of water

Air Velocity in Ducts, (ft/min)	2,399	3,456	3,638	2,938
	2,735	3,599	4,325	2,987
	2,762	3,538	4,325	3,035
	2,762	3,518	3,979	2,938
	2,813	3,393	3,128	2,914
	3,329	2,914	2,487	3,793
	3,393	2,889	2,889	4,646
	3,350	3,011	3,435	4,946
	3,456	2,762	3,793	5,089
	3,599	2,545	3,793	5,089
Average Velocity in Ducts, (ft/min)	3,410			
Standard Deviation of Velocity	695.5			
% Relative Standard Deviation	20.4			
Volume of Air through Ducts, (CFM)	14,867			

Air Velocity in Containment, (ft/min)	300	300	150
	400	500	600
	700	700	800
Average Air Velocity in Containment, (ft/min)	494		
Standard Deviation of Air Velocity in Containment	221.4		
% Relative Standard Deviation	44.8		
Volume of Air through Containment, (CFM)	24,700		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type:	Parallel with Dance Floor
Air Input Type:	Low-Speed High-Volume Fan
Dust Collector:	509.7 m^3/min (18,000 CFM) @ 2,100 RPM
Negative Pressure Obtained:	2.54 mm (0.1 in) of water

Air Velocity in Ducts, (ft/min)	3,058	3,563	3,579	3,285
	3,414	3,456	3,979	3,151
	3,456	3,497	4,155	2,963
	3,456	3,477	3,793	2,813
	3,285	3,393	3,285	2,682
	3,558	2,709	3,817	3,196
	3,697	2,369	2,338	3,755
	3,599	2,276	2,709	4,646
	3,678	2,212	3,307	4,325
	3,435	2,146	2,938	4,325
Average Velocity in Ducts, (ft/min)	3,319			
Standard Deviation of Velocity	590.6			
% Relative Standard Deviation	17.8			
Volume of Air through Ducts, (CFM)	14,470			

Air Velocity in Containment, (ft/min)	300	300	250
	700	600	700
	900	700	700
Average Air Velocity in Containment, (ft/min)	572		
Standard Deviation of Air Velocity in Containment	230.6		
% Relative Standard Deviation	40.3		
Volume of Air through Containment, (CFM)	28,000		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Containment Type: Perpendicular to the Ground
Air Input Type: Baffle with Ducts on the Ground into Containment
Dust Collector: 566.34 m^3/min (20,000 CFM) operated @ 2,100 RPM
Negative Pressure Obtained: 3.81 mm (0.15 in) of water

Air Velocity in Ducts, (ft/min)	3,330	4,581	3,713	5,475
	3,548	4,742	3,852	5,337
	3,611	4,742	3,872	5,337
	3,734	4,742	3,852	5,337
	3,872	4,414	4,241	5,610
	4,581	3,353	4,581	5,871
	4,581	2,738	4,742	5,742
	4,241	2,323	4,742	5,610
	4,241	2,323	4,742	5,742
	4,241	2,568	4,241	5,610
Average Velocity in Ducts, (ft/min)	4,369			
Standard Deviation of Velocity	951.1			
% Relative Standard Deviation	21.8			
Volume of Air through Ducts, (CFM)	19,048			

Air Velocity in Containment, (ft/min)	300	200	50
	350	200	150
	300	200	200
	450	300	300
	400	350	450
Average Air Velocity in Containment, (ft/min)	280		
Standard Deviation of Air Velocity in Containment	113.1		
% Relative Standard Deviation	40.4		
Volume of Air through Containment, (CFM)	18,480		

1 ft/min = 0.3 m/min
1 CFM (ft^3/min) = 0.028 CMM (m^3/min)

Table 79. Summary of results of blasting tests.

Test Date	Abrasive	Containment Type[2]	Negative Pressure, mm (in) H_2O	Air Velocity,[3] m/min (ft/min)	Worker Exposure	Production Rate, m^2 (ft^2)
3-26-93[1]	Min Sand	Per-P	2.54 (0.1)	92.96 (305)	3,500	2.83 (30.5)
3-29-93	Min Sand	Per-P	2.29 (0.09)	80.77 (265)	10,690	5.43 (58.5)
4-14-93	Steel Grit	Per-P	1.02 (0.04)	106.68 (350)	15,314	11.90 (128)
4-21-93	Steel Grit	Per-G	1.02 (0.04)	52.43 (172)	5,886	8.69 (93.5)
4-6-93	Min Sand	Par-G	0.76 (0.03)	28.35 (93)	8,652	5.30 (57)
4-13-93	Steel Grit	Par-G	0.76 (0.03)	18.29 (60)	19,667	11.8 (127)
4-23-93	Steel Grit	Par-P	0.76 (0.03)	62.48 (205)	4,254	7.34 (79)
4-27-93[2]	Min Sand	Par-P	0.89 (0.035)	30.48 (100)[4]	15,455	6.04 (65)
5-26-93	Min Sand	Par-P	1.78 (0.07)	54.86 (180)	9,227	6.32 (68)

[1] Due to startup problems, the data are presented for completeness only. They were not used as a basis for conclusions.

[2] Per-P = perpendicular to beams with suspended platform floor.
Per-G = perpendicular to beams with side to the ground.
Par-P = parallel to beams with suspended platform.
Par-G = parallel to beams with sides to the ground.

[3] Calculated from measuring air velocity in the ducts.

[4] This test was performed using high-volume fans and dust socks: The air velocity reported was measured with an anemometer.

DISCUSSION

The size of containment has an obvious effect on the speed of the air moving through containment, not the quantity of air or the uniformity of movement. The exposure data and air movement measurements indicate that no matter what orientation/air velocity was tested, the worker will be exposed above the maximum allowable exposure limit assigned for the type CE continuous-flow blasting hood (1250 $\mu g/m^3$). The interferences due to common members found in bridges and the deck and eddy currents caused by the blasting operation itself limit the ability of the ventilation airflow to remove the dust particles from containment. Even on bridges with 5 percent lead (assuming a linear relationship between lead exposure and lead content), it appears there will be sufficient airborne lead to cause the blaster to be exposed to levels over the 1250 $\mu g/m^3$ limit outside the hood.

While it is easiest to ventilate small areas, it may also be easier to reintroduce lead into the air. Solid floors provide easy access to the blasted surface, but collect spent abrasive. Stray blasting currents stirred up the accumulated abrasive on the floor and reintroduce settled dust. Small platform containments that have an open-grating floor would solve this problem and the problem of increased load on the structure due to the weight of the spent abrasive. In large containments, the problem would not be as severe since the accumulated debris would be removed from the immediate work area.

APPENDIX G. DUCT VELOCITY

The more accurate method of measuring average air velocity through containment is by measuring air velocity through the exhaust ducts. The following is a detailed procedure and other useful information.

1.0 Equipment

1.1 Digital manometer - (Alnor 530 or equivalent) does not require calibration, hand held, LCD display, and can be moved about while taking readings.

1.2 Liquid manometer - (Dwyer 400-10) does not require calibration, must be placed on a vibration-free platform, and leveling adjustment must be made.

NOTE: Either manometer is acceptable. Only one is needed.

1.3 Pitot tube - 8-mm (5/16-in) Outer Diameter (O.D.) should be used unless the duct diameter is less than 305 mm (12 in).

a. There are different lengths of pitot tubes. It is much easier to measure if the pitot tube chosen will reach across the diameter of the exhaust duct measured. Measuring from both sides of the duct is possible, but very slow.

b. Flexible tubing - 5.0 mm (3/16 in) diameter.

(1) Carry enough tubing to allow for moving and adjusting the pitot tube with the manometer placed in a convenient location so the data can be collected.

(2) Two lengths of tubing are needed for attaching the pitot tube to the manometer.

1.4 Exhaust ducts - a section of straight run of duct is needed to make accurate measurements.

2.0 Location of Measurement

2.1 Air velocity measurements must be taken 7.5 duct diameters downstream from any disturbances, e.g., elbows. Experience has shown that three or more duct diameters upstream from any disturbance results in more consistent readings.

3.0 Pitot Traverse Method

3.1 Two traverses of the pitot tube are taken across the diameter of the duct at right angles to one another.

NOTE: The location chosen for making the measurements must allow sufficient room for rotating and inserting the pitot tube into both holes put into the duct 90 degrees apart.

3.2 Ducts larger than 152 mm (6 in) diameter require 10 readings across the diameter of the duct.

3.3 The distance from the wall of the duct to the reading point is determined by the diameter of the duct.

3.4 The diameter of the duct is multiplied by 10 conversion factors that are then rounded to the nearest 3.2 mm (1/8 in). Measurement points for a 406-mm (16-in), 457-mm (18-in), 508-mm (20-in), 635 mm (24-in), or 762-mm (30-in) duct are contained in table 80. Conversion factors for any size duct are contained in table 81.

Table 80. Duct measurement locations using a pitot tube.

Duct diameter	Measurement points for a 10-point traverse (all measurements in inches)									
16	⅜	1¼	2⅜	3⅝	5½	10½	12⅜	13⅝	14¾	15⅝
18	½	1½	2⅝	4⅛	6⅛	11⅞	13⅞	15⅜	16½	17½
20	½	1⅝	2⅞	4½	6⅞	13⅛	15½	17⅛	18⅜	19½
24	⅝	2	3½	5½	8¼	15¾	18½	20½	22	23⅜
28	¾	2¼	4⅛	6⅜	9⅝	18⅜	21⅝	23⅞	25¾	27¼
30	¾	2½	4⅜	6¾	10¼	19¾	23¼	25⅝	27½	29¼

1 in = 25.4 mm

Table 81. Measuring point for other duct sizes.[1]

1	2	3	4	5	6	7	8	9	10
0.026	0.082	0.146	0.226	0.342	0.658	0.774	0.854	0.918	0.974

[1] Multiply each measuring point by the duct diameter to obtain insertion distance.

NOTE: The 10 measured points can quickly be referenced on the pitot tube, by placing a piece of tape (duct or electrical) at the increments required by the duct diameter on the pitot tube.

4.0 Measurements

4.1 Before taking any measurements, the manometer must be zeroed. Follow instructions from manual.

4.2 Drill or cut two holes into the duct that are 90 degrees apart. The holes shall be large enough to insert the pitot tube.

NOTE: While one technician can read the digital manometer, adjust the pitot tube, and record the measurements, two technicians can take the same measurements in less than half the time of one technician. The measured results from two technicians tend to be more accurate since the pitot tube can be adjusted correctly at all times and the manometer reading can be monitored more effectively.

NOTE: A liquid manometer will almost always require two technicians. Since the manometer must be stationary at all times during measurements, it is difficult to place the manometer on a flat surface where the technician can read the scale and at the same time ensure that the pitot tube is adjusted at the correct distance.

4.3 The pitot tube should be placed in the duct with the end of the tube facing into the air stream.

NOTE: If negative readings are obtained, the tubing connecting the pitot tube to the manometer were attached incorrectly. Reverse the tubing on either the pitot tube or manometer.

a. Thick-wall, flexible tubing should be employed. Hard plastic tubing is difficult to maneuver, while very thin-wall, flexible tubing collapses easily.

4.4 Once a maximum velocity is achieved at a traverse point, the data is recorded. The pitot tube is then positioned for the next measurement until all 10 are completed. This same procedure is followed for the other 10 points.

5.0 Calculating Air Velocity in a Duct

5.1 Convert velocity pressure (VP) to velocity (V) using the equation $V=4005(VP)^{½}$, where VP is expressed in inches of water column and V is expressed in ft/min.

NOTE: A conversion table can be found in most industrial ventilation manuals.

5.2 Average the 20 measurements and determine the average air velocity through the duct.

NOTE: Seventy-five percent (75%) of the measurements should be greater than 10 percent of the maximum measurement. If this criteria is not achieved, airflow distribution in the duct is not uniform. Retake the measurements at a different location.

NOTE: The minimum recommended velocity to keep the dust entrained in the air while moving through a duct is 1219 m/min (4,000 ft/min).

6.0 Calculating Average Air Velocity through Containment

6.1 Measure the air velocity in the duct for each duct connecting containment to the dust collectors(s).

6.2 Calculate the quantity of air (Q) moving through the duct using the equations $Q=3.14r^2V$, where r is the radius of the duct and V is the average velocity measured.

6.3 Determine the cross-sectional area of the containment perpendicular to the direction of the airflow. Divide the quantity of air (Q) calculated in 6.2 by this cross-sectional area. The result is the average velocity of air in containment.

NOTE: The value calculated is an average. This does not indicate whether the airflow through containment is uniform.

APPENDIX H. ANALYTICAL TEST METHODS

LEAD IN PAINT CHIPS PROCEDURE

ASTM D3335-85a

1.0 Purpose: To determine the total percentage by weight of lead in a dried paint sample.

2.0 Equipment

- 2.1 ICP
- 2.2 Muffle furnace capable of maintaining 500 +/-10 °C
- 2.3 Crucibles: wide-form, porcelain, glazed, approximately 30-mL capacity
- 2.4 Hotplate with a surface temperature range from 70 to 200 °C
- 2.5 Volumetric flasks, 100 mL and 1000 mL
- 2.6 Pipets - various capacities
- 2.7 Whatman 41 filter paper
- 2.8 Analytical balance capable of accurately weighing to 0.0001 g

3.0 Reagents

- 3.1 ASTM Type II water
- 3.2 Ammonium Acetate Solution (50% weight/volume): dissolve 500 g of ammonium acetate ($NH_4C_2H_3O_2$) in Type II water and dilute to 1 L.
- 3.3 Nitric Acid, conc. (sp. gr. 1.42)
- 3.4 Nitric Acid, 1+1: add one volume of HNO_3 (sp. gr. 1.42) to one volume Type II water.

4.0 Procedure

- 4.1 Weigh 0.5 to 2 g of dried paint in a tared 30-mL porcelain crucible.
  - 4.1.1 Record weight to the nearest 0.1 mg.
- 4.2 Place on hotplate, set the temperature on high, and heat until charring occurs.
- 4.3 Place in a muffle furnace pre-heated to 475 to 500 °C to ash.
  - 4.3.1 Pre-heating muffle furnace.
  - 4.3.2 Do not exceed 500 °C or some lead may be lost by volatilization.
  - 4.3.3 Do not exceed 1 to 2 h ashing time.
- 4.4 Remove crucible from furnace and allow to cool to room temperature.
- 4.5 Break up ash into fine particles with a glass stirring rod.
- 4.6 Add 10 mL of HNO_3 (1+1).
  - 4.6.1 Use some of this 10 mL HNO_3 to rinse the glass stirring rod, adding the

rinsate to the crucible.

4.6.2 Add carefully to avoid loss of sample due to spattering in case the sample reacts vigorously.

4.7 Heat carefully without boiling until 2 or 3 mL of solution remain.

4.8 Add an additional 10 mL of HNO_3 (1+1) and continue heating on the hotplate until less than 5 mL remain.

4.9 Filter through Whatman 41 filter paper into a 100-mL volumetric.

4.10 Rinse the crucible three times with hot ammonium acetate solution, each time transferring the rinsate to the filter paper.

4.11 Rinse the crucible three times with Type II water, each time transferring the rinsate to the filter paper.

4.12 Adjust the volume to 100 mL with Type II water and mix.

4.13 Analyze by ICP using a 10-ppm standardization.

4.13.1 Dilute all samples over the linearity range.

5.0 Calculation

5.1 The mean concentration of lead, ppm = (C x F x 10,000)/NV x S where:

C = concentration derived from ICP, (μg/mL)
F = dilution factor (see 4.13.1)
10,000 = factor derived from multiplying the 100-mL volume by 100 (to convert NV used to a whole number) and 10^6 (to obtain ppm), then dividing by 10^6 (to convert grams of sample to μg) NV = 100 (for dried film), S = sample, grams

5.2 Percent by weight (%) = ppm/10,000

ACID DIGESTION OF SEDIMENTS, SLUDGES, AND SOILS

EPA Method 3050

1.0 Purpose: To prepare sediments, sludges, and soils for analysis by ICP to determine total specified metal concentration of the sample. Generally lead is the element of interest.

2.0 Equipment

- 2.1 250-mL beakers
- 2.2 Watch glasses
- 2.3 Drying oven
- 2.4 Whatman 41 filter paper
- 2.5 Analytical balance capable of accurately weighing to 0.01 g
- 2.6 Hotplate: adjustable and capable of maintaining a temperature of 90 to 95 °C
- 2.7 Glass funnels
- 2.8 Volumetric flasks, 100 mL
- 2.9 Pipets - various capacities

3.0 Reagents: Reagent-Grade Chemicals Only

- 3.1 ASTM Type II water
- 3.2 HNO_3, conc.
- 3.3 HNO_3, 1+1: add one volume of HNO_3, conc., to one volume of Type II water.
- 3.4 HCl, conc.
- 3.5 H_2O_2 (30%)

4.0 Sample Preparation for Soils

- 4.1 If the sample arrives wet, place in an oven set @ 95 ^{0}C until dry.
- 4.2 Mix the sample thoroughly.
- 4.3 Sieve if necessary to remove debris that is not soil.

5.0 Procedure

- 5.1 Weigh 1 to 2 g of sample into a tared 250-mL beaker.
  - 5.1.1 Record weight to the nearest 0.1 mg.
  - 5.1.2 The minimum sample size is 0.250 mg.
- 5.2 Add 10 mL of HNO_3, 1+1.
- 5.3 Cover with a watch glass.
- 5.4 Heat sample to 95 °C and reflux for 10 to 15 min without boiling.
- 5.5 Allow sample to cool.
- 5.6 Add 5 mL HNO_3, conc., and replace watch glass.
- 5.7 Reflux for 30 min.

5.8 Add 5 mL HNO_3, conc.

5.9 Reflux for another 30 min allowing solution to evaporate to 5 mL without boiling and maintaining a covering of solution over the bottom of the beaker.

5.10 Cool sample.

5.11 Add: 2 mL Type II H_2O
3 mL H_2O_2, 30%

5.12 Return beaker to the hotplate for warming and to start peroxide reaction.

5.13 Heat until effervescence subsides and cool beaker.

5.14 Continue adding 30% H_2O_2 in 1-mL aliquots with warming until effervescence is minimal or until the general sample appearance is unchanged.

5.14.1 Do not add more than a total of 10 mL of 30% H_2O_2

5.15 Add: 5 mL HCl, conc.
10 mL Type II H_2O

5.16 Return to hotplate and reflux for an additional 15 min without boiling.

5.17 Cool.

5.18 Quantitatively transfer sample to a 100-mL volumetric and dilute to 100 mL with Type II H_2O.

5.19 Particulates that may clog the nebulizer should be removed by filtration, centrifugation, or by allowing the sample to settle.

5.20 Sample is ready for ICP analysis.

5.20.1 Dilute all samples over the linearity range.

6.0 Calculation

6.1 The mean concentration of analyte, mg/kg = (C x F x 10,000)/NV x S where:

C = concentration derived from ICP, (μg/mL)
F = dilution factor (see 5.20.1)
10,000 = factor derived from multiplying the 100-mL volume by 100 (to convert NV used to a whole number) and 10^6 (to convert grams of sample to μg)
NV = 100 (= nonvolatile and the sample was dry or dried)
S = sample, grams

6.2 Percent by weight (%) - ppm/10,000

LEAD IN PAINT BY HOTPLATE-BASED ACID DIGESTION

NIOSH 7082-2

1.0 Purpose: To determine the total percentage by weight of lead in a dried paint sample by modifying an air-monitor filter procedure.

2.0 Equipment

2.1 125-mL Phillips beakers
2.2 Watch glasses
2.3 Drying oven
2.4 Whatman #41 filter paper
2.5 Analytical balance capable of accurately weighing to 0.0001 g
2.6 Hotplate: adjustable and capable of maintaining a temperature of 140 °C
2.7 Glass funnels
2.8 Volumetric flasks, 100 mL
2.9 Pipets - various capacities

3.0 Reagents: Reagent-Grade Chemicals Only

3.1 ASTM Type II water
3.2 HNO_3, concentrated
3.3 HNO_3, 10% (w/v): add 100 mL of concentrated nitric acid to 500 mL of de-ionized water; dilute to 1 L.
3.4 Hydrogen Peroxide: 30% H_2O_2, w/w

4.0 Procedure

4.1 Weigh 1 g (nearest milligram) of sample into a tared 125-mL Phillips beaker.
4.2 Add 3 mL conc. HNO_3 and 1 mL 30% H_2O_2.
4.3 Heat on 140 °C hotplate until most of the acid has evaporated.
4.4 Remove from hotplate and cool.
4.5 Repeat this process two more times using 2 mL conc. HNO_3 and 1 mL 30% H_2O_2.
4.6 After last addition, evaporate to dryness.
4.7 Rinse walls of beaker with 3 to 5 mL 10% HNO_3.
4.8 Return sample to hotplate and evaporate gently to dryness.
4.9 Cool beaker and add 10 mL conc. HNO_3 to dissolve the residue.
4.10 Set up glass funnels over 100-mL pre-labeled volumetric flasks.
4.11 In each funnel, place a folded Whatman #41 filter paper.
4.12 Filter: first decant the liquid, then empty the solids onto the filter paper.
4.13 With de-ionized water, rinse the beaker three times, adding each wash to the filter paper.
4.14 Dilute to volume with de-ionized water.

5.0 Sample Analysis by ICP or AAS

5.1 See specific instrument protocol for specifics of analysis.
5.2 Dilute all samples over the linearity range.

6.0 Calculation

6.1 The mean concentration of analyte, $\mu g/g = (C_{TS} \times V_{TS})/M_{SA}$ where:

C_{TS} = lead concentration in test solution, corrected for dilution, μg/mL
V_{TS} = volume of sample digest solution, mL
M_{SA} = mass of sample aliquot digested, g

6.2 μg/g = mg/kg; Report as mg/kg.

LEAD IN PAINT BY HOTPLATE-BASED ACID DIGESTION

PB92-114172

1.0 Purpose: To determine the total percentage by weight of lead in a dried paint sample.

2.0 Equipment

2.1 125-mL Phillips beakers
2.2 Watch glasses
2.3 Drying oven
2.4 Whatman #54 filter paper
2.5 Analytical balance capable of accurately weighing to 0.0001 g
2.6 Hotplate: adjustable and capable of maintaining a temperature of 140 °C
2.7 Glass funnels
2.8 Volumetric flasks, 100 mL
2.9 Pipets - various capacities

3.0 Reagents: Reagent-Grade Chemicals Only

3.1 ASTM Type II water
3.2 HNO_3, concentrated
3.3 HNO_3, 10% (w/v): add 100 mL of concentrated nitric acid to 500 mL of de-ionized water; dilute to 1 L.
3.4 Hydrogen Peroxide: 30% H_2O_2, w/w

4.0 Procedure

4.1 Weigh 0.1 g (nearest milligram) of sample into a tared 125-mL Phillips beaker.
4.2 Add 3 mL conc. HNO_3 and 1 mL 30% H_2O_2.
4.3 Heat on 140 °C hotplate until most of the acid has evaporated.
4.4 Remove from hotplate and cool.
4.5 Repeat this process two more times using 2 mL conc. HNO_3 and 1 mL 30% H_2O_2.
4.6 After last addition, evaporate to near dryness.
4.7 Rinse walls of beaker with 3 to 5 mL 10% HNO_3.
4.8 Evaporate gently to dryness.
4.9 Cool beaker and add 1 mL conc. HNO_3 to dissolve the residue.
4.10 Set up glass funnels over 100-mL pre-labeled volumetric flasks.
4.11 In each funnel, place a folded Whatman #54 filter paper.
4.12 Before filtering, wet filter paper and rinse glassware with 20 to 30 mL of de-ionized water; discard the rinse water.
4.13 Filter: first decant the liquid, then empty the solids onto the filter paper.
4.14 With de-ionized water, rinse the beaker three times with small (3 mL) portions of water, adding each wash to the filter paper.
4.15 Rinse the filter three times with small (3 mL) portions of water.
4.16 Discard the filter after it has thoroughly drained and rinse the funnel with one small

portion of water.

4.17 Dilute to volume with de-ionized water.

5.0 Sample Analysis by ICP or AAS

5.1 See specific instrument protocol for specifics of analysis.

5.2 Dilute all samples over the linearity range.

6.0 Calculation

6.1 The mean concentration of analyte, mg/kg = $(C_{TS} \times V_{TS})/M_{SA}$ where:

C_{TS} = lead concentration in test solution, corrected for dilution, μg/mL
V_{TS} = volume of sample digest solution, mL
M_{SA} = mass of sample aliquot digested, g

6.2 μg/g = mg/kg; Report as mg/kg.

APPENDIX I. WASTE FACILITES MANAGING METAL WASTES.[1]

COMPANY	CITY
Alabama	
Ashland Chemical Co.	Birmingham
CWM-Emelle	Emelle
ILCO, Inc.	Leeds
M&M Chemical & Equipment Co., Inc.	Reece City
Arizona	
Buds Oil Service, Inc.	Phoenix
CWM-Phoenix	Phoenix
Environmental Waste Ent., Inc.	Eloy
Arkansas	
Lion Oil Company	El Dorado
National Bumper Exchange	West Memphis
California	
Appropriate Technologies	Chula Vista
Bay Area Environmental Inc.	Richmond
Casmalla Resources	Casmalla
Chemwest Industries, Inc.	Cloverdale
Crosby & Overton, Inc.	Long Beach
CWM-Kettleman City	Kettleman City
GNB, Inc.	Los Angeles
Imperial West Chemical Company	Antioch
IT Corp. Amorco Facility	Martinez
IT Corp. Baker Facility	Martinez
IT Corp. Benicia Facility	Benicia
IT Corp. Imperial Facility	Westmorland
IT Corp. No. CA Services	Martinez

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[1] Obtained from *Directory of Commercial Hazardous Waste Management Facilities*, EPA Report No. EPA/530-SW-87-024, U.S. Environmental Protection Agency, Washington, DC, August 1987.

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
California (continued)	
IT Corp. Oil Reprocess Facility	Martinez
IT Corp. San Jose Transfer Facility	San Jose
IT Corp. Vine Hill	Martinez
IT Transportation Corp. Taft Facility	Taft
IT Transportation Corp. Wilmington	Wilmington
Norris Industries, Inc.	Los Angeles
Omega Chemical Corp.	Whittier
Orange County Chemical Corp.	Santa Ana
Pacific Treatment Corp.	San Diego
Quemetco, Inc.	City of Industry
Solvent Service, Inc.	San Jose
Southern California Chemical Co., Inc.	Santa Fe Springs
Turco Products, Inc.	Carson
Connecticut	
American Chemical & Refining Company	Waterbury
Cecos International Inc.	Bristol
City of Danbury	Danbury
Connecticut Treatment Corp.	Bristol
East Coast Environmental Service Corp.	New Haven
Envirite Corporation	Thomaston
Environmental Waste Resources, Inc.	Waterbury
Handy & Harman Fairfield Plant	Fairfield
MacDermid Inc.	Waterbury
Porters Grove Metal Recovery Co.	Bridgeport
Printing Developments Inc.	East Granby
Florida	
Ashland Chemical Co.	Tampa
CWM Inc.	Pompano Beach
Porters Grove Metal Recovery S.E.	Lakeland
Georgia	
Ashland Chemical Co.	Doraville
Chemical Products Corp.	Cartersville
IMC	Augusta
International Minerals & Chemical Corp.	Americus

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Georgia (continued)	
Solidtek Inc. Systems Inc.	Morrow
Trichem Company	Atlanta
Hawaii	
Unitek Environmental Services Inc.	Ewa Beach
Idaho	
Envirosafe	Grand View
Illinois	
American Waste Processing Ltd.	Maywood
Cecos International Inc./BFI Ind. of Illinois	Zion
Chem-Clear Inc.	Chicago
CWM-CID	Calumet City
CWM-Sauget	Sauget
CWM-SCA Chicago-Chemical Services Inc.	Chicago
Envirite Corporation	Harvey
Northrop Corp. Defense Systems Div.	Rolling Meadows
Peoria Disposal Co.	Peoria
Petrochem Services, Inc.	Lemont
United Ind. Syndicate Air Tex Prod. Div.	Fairfield
Indiana	
Ashland Chemical Co.	Indianapolis
CWM-Adams Center Landfill	Fort Wayne
Four County Landfill	Rochester
I.J. Recycling	Fort Wayne
ILWD Inc.	Indianapolis
Quemetco, Inc.	Indianapolis
Stauffer Chemical Co.	Hammond
Iowa	
Salsbury Laboratories	Charles City

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Kansas	
Conservation Services, Inc.	Wichita
Deffenbaugh Disposal Service	Shawnee
Kentucky	
Ashland Chemical Co. - IC&S Division	Catlettsburg
Custom Industrial Services Inc.	Shelbyville
Kyana Oil, Inc.	Louisville
M & T Chemicals, Inc.	Carrollton
Pennwalt Corp.	Calvert City
Louisiana	
Cecos International Inc.	Westlake
CWM-Carlyss	Carlyss
Rollins Environmental Services Inc.	Baton Rouge
Rollins Environmental Services of LA Inc.	Plaquemine
Maryland	
Capital Assay Labs, Ltd.	Baltimore
Chem-Clear Inc. of Baltimore	Baltimore
GSX Services Inc.	Laurel
Massachusetts	
Clean Harbors of Braintree, Inc.	Braintree
Clean Harbors of Natick Inc.	Natick
General Metal Finishing Co., Inc.	Attleboro
Geochem D/B/A Jet-Line of Lowell	Lowell
Matheson Gas Products Inc.	Gloucester
Northeast Solvents Corp.	Lawrence
Michigan	
Chem-Met Services, Inc.	Wyandotte
Environmental Waste Control Inc.	Inkster
Michigan Disposal Inc. (WPF)	Belleville
Nelson Industrial Services	Detroit
Petro-Chem Processing Inc.	Detroit

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Michigan (continued)	
Trail Environmental Services, Inc.	Muskegon Heights
Waste Acid Service Inc.	Detroit
Wayne Disposal, Inc. Site #2	Bellevile
Minnesota	
Federal-Hoffman, Inc.	Anoka
North Star Steel Co.	St. Paul
Mississippi	
Ashland Chemical Co.	Jackson
Missouri	
Ashland Chemical Co.	St. Louis
B.H.S. Inc.	Wright City
Conservation Chemical Co.	St. Louis
Reclamare Enterprises	Kansas City
Resource Recovery Center	Columbia
Solvent Recovery Corporation	Kansas City
Montana	
Burlington Northern Somers Tie Plant	Somers
Nevada	
US Ecology Inc. Chem Site	Beatty
New Hampshire	
Coating Systems, Inc.	Nashua
New Jersey	
Advanced Env Tech Corp.	Flanders
CWM-SCA Newark-Chemical Services Inc.	Newark
Dupont E. I. De Nemours, Chamber Works	Deepwater
Emergency Technical Services Corp.	Vernon

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
New Jersey (continued)	
Givaudan Corporation	Alifton
OMI International Corp.	Nutley
Pass Recovery Systems Inc.	Clifton
Perk Chemical Company, Inc.	Elizabeth
Pittsburg Metal & Equipment Co.	Jersey City
Plasti-Clad Metal Products Inc.	Wall
S&W Waste, Inc.	South Keamy
Spectraserv, Inc.	Keamy
Vanguard Research Associates, Inc.	South Plainfield
New York	
BDT, Inc.	Clarence
Cecos International Inc.	Niagara Falls
Chemical Management	Farmingdale
Chemical Pollution Control	Bay Shore
Chemical Waste Disposal	Astoria
Frontier Chemical Waste Process, Inc.	Niagara Falls
General Waste Oil Co., Inc.	Wyandanch
Haz-O-Waste Corporation	Wampsville
Lehigh Portland Cement Co.	Cementon
Radiac Research	Brooklyn
Revere Smelting and Refining Corp.	Middletown
SCA Chemical	Model City
North Carolina	
Ashland Chemical Co.	Charlotte
Ashland Chemical Co.	Greensboro
Ashland Chemical Co.	Raleigh
Caldwell Systems Inc.	Lenoir
GSX Services, Inc.	Reidsville
Lithium Corp of America Chemical Plant	Bessemer City
Ohio	
Alchem-Tron Inc.	Cleveland
Ashland Chemical Co.	Akron
Ashland Chemical Co.	Columbus
Ashland Chemical Co.	Evendale

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Ohio (continued)	
Cecos International Inc.	Cincinnati
Cecos International Inc.	Williamsburg
Chem-Clear Inc.	Cleveland
CWM-Vickery	Vickery
Delhi Industrial Products	McDonald
Dupont E.I. De Nemours & Co.	Cleveland
Envirite Corporation	Canton
Environmental Enterprises Inc.	Cincinnati
Erieway Pollution Control Inc.	Bedford
F.E.I. Landfarming, Site 2	Oregon
Fondessy Enterprises Inc.	Oregon
General Portland Inc. Paulding Plant	Paulding
General Tire & Rubber Co.	Toledo
Master Metals Inc.	Cleveland
Samsel Service Co.	Cleveland
Trail Environmental Services, Inc.	Hillard
Oklahoma	
Ashland Chemical Co.	Oklahoma City
Eagle Picher Industries Inc. EOM Dept	Quapaw
USPCI	Waynoka
Oregon	
CWM-Chem-Security Systems Inc.	Arlington
Pennsylvania	
AMC Pollution Services Inc.	Canonsburg
Ashland Chemical Co.	Freedom
C&D Power Systems, Inc.	Conshohocken
Chem-Clear Inc.	Chester
Delaware Container Co., Inc.	Coatsville
East Penn Manufacturing Co., Inc.	Lyon Station
Envirite Corporation	York
Harley-Davidson Motor Co., Inc.	York
Industrial Solvents and Chemical Co.	York Haven
Industrial Waste Removal Inc.	Lewisberry
International Metals Reclamation Co., Inc.	York Haven

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Pennsylvania (continued)	
Keystone Chemical Co.	Giradville
Marcus Hook Processing Inc.	Marcus Hook
Mill Service Inc.	Bulger
Mill Service Inc. Yukon Plant	Yukon
New Hersey Zinc Company	Palmerton
Waste Conversion Inc.	Harfield
WRC Processing Company	Pottsville
Puerto Rico	
Proteco	Penuelas
Thermo King Caribbean, Inc.	Ciales
Rhode Island	
Boliden Metech Inc.	Mapleville
Fort Barton Holdings Inc.	Warwick
International Depository Inc.	North Kingstown
Narragansett Improvement Company	Providence
Northland Chemical Company	Providence
South Carolina	
Ashland Chemical Co.	Greenville
CP Chemicals Inc.	Sumter
Groce Laboratories	Greer
GSX Services of South Carolina, Inc.	Pinewood
GSX Thermal Oxidation Corp. (ABCO Ind.)	Roebuck
Stablex South Carolina Inc.	Rock Hill
Tennessee	
Diversified Systems, Inc. Storage Facility	Athens
Earth Industrial Waste Management	Millington
GSX Services Inc.	Greenbrier
Industrial Liquids Recycling Inc.	Mt. Pleasant
Tricil Environmental Services, Inc.	Antioch
Yale Security Inc. (Scovill)	Lenoir City

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
Texas	
Ashland Chemical Co.	Garland
Ashland Chemical	Houston
Cecos International Inc.	Odessa
CWM-Corpus Christi	Corpus Christi
CWM-Port Arthur	Port Arthur
Diamond Shamrock Chemicals Company	Deer Park
Disposal Systems Inc.- Deer Park Facility	Deer Park
Eltex Chemical & Supply Company	Houston
Empak Inc. Deer Park	Deer Park
Gibraltar Chemical Resources	Winona
Gulf Coast Waste Disposal Authority	Texas City
GNB Batteries, Inc.	Frisco
Malone Service Company	Texas City
Olin Corporation	Beaumont
Paktank Gulf Coast Inc. Deer Park	Deer Park
Petro Processors, Inc.	San Leon
Rollins Environmental Services of TX, Inc.	Deer Park
Standard Industries	San Antonio
Texas Ecologists, Inc.	Robstown
Torque Petroleum Products	San Leon
Utah	
Ekotek Inc.	Salt Lake City
USPCI Grassy Mt. Facility	Knowles
Virginia	
Ashland Chemical Co.	Roanoke
Washington	
Chemical Processors, Inc.	Seattle
Chemical Processors, Inc.	Tacoma
Crosby & Overton, Inc. Plant 2	Kent
McClary Columbia Corp.	Washougal
Northwest Enviroservice, Inc.	Seattle

APPENDIX I. WASTE FACILITIES MANAGING METAL WASTES (continued).

COMPANY	CITY
West Virginia	
Weirton Steel Corp.	Weirton
Wisconsin	
Aqua-Tech, Inc.	Port Washington
Ashland Chemical Co.	Menasha
CWM-Menomonee Falls	Menomonee Falls
Milwaukee Solvents & Chemicals Corp.	Menomonee Falls
Printing Development Inc.	Racine
Zimpro Inc.	Rothschild

APPENDIX J. DISPOSAL COSTS AT SELECTED HAZARDOUS WASTE FACILITIES

Facility	Cost	Treatment Method	Comments
Mill Service, Inc., Pennsylvania	\$90-\$125/ton	Lime neutralization	Prefer to deal with 3-yd^3 roll-offs. Drums are higher in cost.
Chemical Waste Mgmt. of Indiana	\$260/ton; \$165/drum	Portland cement or lime	Transportation of drums or bulk solid is \$3.95/mile; bulk in roll-off is \$4.10/mile.
Chemical Security Systems, Oregon	\$225/ton; \$178 drum		Transportation for drum and bulk is \$3.60/loaded mile.
Wayne Disposal, Michigan	\$165-\$170/yd^3+MI; \$10 surcharge; \$90/drum		Facility for toxic and non-toxic waste.
Cecos International, Texas	Kiln dust \$240/yd^3;\$225/drum; Kiln dust/cement-\$750-800/yd^3	Kiln dust/cement	Charges a shipping rate depending on location of waste.
Rollins Environmental, Texas	\$420/yd^3;\$165/drum	Fly ash and lime	
Envirosafe Services of Ohio	\$175/ton		
Texas Ecologists, Inc.	\$100/drum; \$105/ton		
Texas Ecologists, Inc.	\$80 disposal; \$110 stabilization	Fly ash and cement	
Adams Center Landfill, Indiana			
McKesson Envirosystem, Kentucky	\$400-\$1000/drum	Incineration	
Chem Met Services, Inc., Michigan	\$250/yd^3; \$120/drum	Lime stabilization and fixation	No problem with land ban.
GSX, Inc., S. Carolina	\$135/ton; \$75/drum		
American Waste Processing, Illinois	Burial: \$250/ton; \$200/drum + freight		
Clean Harbors, Maryland	\$300/ton;\$180/drum. Add transportation to Baltimore		
Chemical Waste Mgmt. of Alabama	\$260/ton; \$27/ton tax		Disposal only - "must stabilize"
Chemical Waste Mgmt. of New York	\$135/ton; \$22/ton tax; \$220/ton; \$27/ton tax		Treat waste to meet "land ban" rule; may have to do additional treatment to meet rule

1 ton = 907 kg

APPENDIX K. COMPLIANCE REQUIREMENTS

THE OSHA CONSTRUCTION INDUSTRY LEAD STANDARD (29 CFR 1926.62)

The OSHA Construction Industry Lead Standard (29 CFR 1926.62) requires that before beginning any work that may result in lead exposure, an employer must determine if any employee may be exposed to lead at or above the action level (30 $\mu g/m^3$). This determination must be in writing and be posted. If any employee may be exposed at or above the action level, the employer must conduct air sampling at the start of the operation that may involve lead exposure.

TRIGGER LEVEL				
Any Airborne Lead	At or Above Action Level (30 $\mu g/m^3$)	Above PEL (50 $\mu g/m^3$)	Compliance Requirements	Ref. Section
			CONDUCT EXPOSURE MONITORING	(d)
x			- at start of job	
	x		- every 6 months	
		x	- every quarter	
x	x	x	- when job change may result in new or additional exposure	
x	x	x	- if employee complains of symptoms related to lead exposure	
			Whenever exposure monitoring is performed, employee must be provided with written notice of results. Workers must be protected during exposure monitoring.	
		x	USE FEASIBLE ENGINEERING AND WORK PRACTICE CONTROLS	(e) (1)
		x	DEVELOP WRITTEN COMPLIANCE PROGRAM AND REVIEW EVERY 6 MONTHS	(e) (2)
			PROVIDE RESPIRATORY PROTECTION	(f)
		x	- to supplement engineering and work practice controls	
		x	- when controls not feasible	
		x	- upon employee request	
			When respirators are provided, a respiratory protection program in accordance with 29 CFR 1910.134 (b), (d), (e) and (f) must be established and fit testing must be conducted. A medical examination must be provided if an employee exhibits difficulty breathing during respirator fit test or use. An employer must provide a powered air-purifying respirator at the employee's request. Respirator protection factors are presented in Table 1 of 29 CFR 1926.62.	(f)

TRIGGER LEVEL				
Any Airborne Lead	At or Above Action Level (30 $\mu g/m^3$)	Above PEL (50 $\mu g/m^3$)	Compliance Requirements	Ref. Section
			PROVIDE APPROPRIATE PROTECTIVE CLOTHING AND EQUIPMENT	(g)
		x	- clean clothing weekly (daily if exposure above 200 $\mu g/m^3$)	
		x	- ensure protective clothing removed at end of shift	
		x	- ensure appropriate laundering or disposal	
		x	- clean and repair equipment	
			Protective clothing and equipment must also be provided when the possibility of skin or eye irritation exists.	
			MAINTAIN ALL SURFACES AS FREE OF LEAD AS POSSIBLE	(h)
x	x	x	- prohibit cleaning by compressed air except with ventilation system	
x	x	x	- use vacuuming or other equally effective cleaning methods	
x	x	x	- use wet or dry sweeping methods when vacuuming not feasible	
		x	PROHIBIT EATING, DRINKING, AND SMOKING IN JOB AREA	(i)
		x	- provide eating and drinking area	
		x	- ensure employees wash prior to eating or drinking	
		x	- ensure employees entering eating area are as free as practical from lead contamination	
			PROVIDE CHANGE AREAS AND STORAGE	(i)
		x	- ensure employees do not leave job area in contaminated clothes	
		x	- provide shower facilities	
			PROVIDE WASH FACILITIES (29 CFR 1926.51)	(f)(i)
x	x	x	- be sure employees wash at breaks, and at end of shift if shower facilities are not feasible	
			INSTITUTE MEDICAL SURVEILLANCE PROGRAM	(j)
			Biological monitoring (Blood Lead + ZPP Levels)	
	x	x	- prior to assignment	
	x	x	- every 2 months for first 6 months of exposure	
	x	x	- written notification of results to employee	
			Medical examination must be provided when exposure is above action level and employee has developed signs or symptoms associated with lead intoxication, desires advice on effects of exposure on ability to procreate, or employee's blood lead level is at or above 40 $\mu g/100$ g. A medical examination must also be provided when an employee exhibits difficulty breathing during respirator fit test or use.	

TRIGGER LEVEL				
Any Airborne Lead	At or Above Action Level (30 $\mu g/m^3$)	Above PEL (50 $\mu g/m^3$)	Compliance Requirements	Ref. Section
			PROVIDE MEDICAL REMOVAL AND PROTECTION	(k)
	x	x	- if blood lead level is at or above 50 $\mu g/100$ dL	
	x	x	- if indicated by a final medical determination	
			Employee cannot be returned to former job status until two consecutive tests indicate a blood lead level at or below 40 $\mu g/dL$. Employer must provide medical removal protection benefits for up to 18 months.	
			PROVIDE TRAINING PROGRAM	(l)
	x	x	- educate employee of hazards on lead, compliance programs, and requirements of the Lead Standard	
	x	x	- make copy of Lead Standard and all its appendixes available to employee	
	x	x	- provide yearly training to employees exposed above action level on any one day a year	
		x	POST-WARNING SIGNS	(m)
			MAINTAIN RECORDS OF	(n)
x	x	x	- initial determination	
x	x	x	- exposure monitoring	
	x	x	- medical surveillance	
	x	x	- medical removal	
			Records must be maintained for a minimum of 30 years.	
			OBSERVATION OF MONITORING	(o)
x	x	x	- permit observation of exposure monitoring by employee or their designated representative	
x	x	x	- provide protective clothing and equipment as required	

This chart is intended to summarize the OSHA Lead in Construction Industry Standard and is not to be interpreted as the complete requirements under the standard.

APPENDIX L. EVALUATION CRITERIA

A wide variety of methods were studied in this project. In order to facilitate comparison, the following rating scheme was developed. It is similar to others in the literature, with the exception that actual values are assigned to descriptive phrases and the actual values used during the tests were used (where possible) to determine the appropriate rating.

The evaluation parameters are as follows:

Lead Release to the Environment

Per Worker

(1)	Very High	Greater than 25 $\mu g/m^3$
(2)	High	Greater than 13.5 $\mu g/m^3$
(3)	Moderate	Greater than 4.5 $\mu g/m^3$
(4)	Low	Greater than 1.5 $\mu g/m^3$
(5)	Very Low	Less than 1.5 $\mu g/m^3$

Per Jobsite

(1)	Very High	Greater than 25 $\mu g/m^3$
(2)	High	Greater than 13.5 $\mu g/m^3$
(3)	Moderate	Greater than 4.5 $\mu g/m^3$
(4)	Low	Greater than 1.5 $\mu g/m^3$
(5)	Very Low	Less than 1.5 $\mu g/m^3$

Lead Exposure to Workers

Production Workers

(1)	Very High	Greater than 2500 $\mu g/m^3$
(2)	High	Greater than 1250 $\mu g/m^3$
(3)	Moderate	Greater than 500 $\mu g/m^3$
(4)	Low	Greater than 50 $\mu g/m^3$
(5)	Very Low	Less than 50 $\mu g/m^3$

Support Personnel

(1)	Very High	Greater than 2500 $\mu g/m^3$
(2)	High	Greater than 1250 $\mu g/m^3$
(3)	Moderate	Greater than 500 $\mu g/m^3$
(4)	Low	Greater than 50 $\mu g/m^3$
(5)	Very Low	Less than 50 $\mu g/m^3$

Inspectors

(1)	Very High	Greater than 2500 $\mu g/m^3$
(2)	High	Greater than 1250 $\mu g/m^3$
(3)	Moderate	Greater than 500 $\mu g/m^3$
(4)	Low	Greater than 50 $\mu g/m^3$
(5)	Very Low	Less than 50 $\mu g/m^3$

Productivity

(1)	Very High	Greater than 7.0 m^2/h (75 ft^2/h)
(2)	High	Greater than 4.6 m^2/h (50 ft^2/h)
(3)	Moderate	Greater than 2.3 m^2/h (25 ft^2/h)
(4)	Low	Greater than 1 m^2/h (10 ft^2/h)
(5)	Very Low	Less than 1 m^2/h (10 ft^2/h)

Containment Requirements

(1)	Very Good	SSPC Class 1 or 2
		(a) SSPC Class 1 or 2 with water collection capabilities
(2)	Good	SSPC Class 3
		(a) SSPC Class 3 with water collection capabilities
(3)	Moderate	SSPC Class 4
		(a) SSPC Class 4 with water collection capabilities
(4)	Low	SSPC Class 5
		(a) SSPC Class 5 with water collection capabilities

Fatigue Factor to Operate

(1)	Very High	Productivity reduced more than 50 percent throughout the workday.
(2)	High	Productivity reduced 50 percent throughout the workday.
(3)	Moderate	Productivity reduced 25 percent throughout the workday.
(4)	Low	Productivity reduced less than 10 percent throughout the workday.
(5)	Very Low	Productivity essentially the same throughout the workday.

Skill Level Required to Operate

(1)	Very High	Requires onsite technician throughout project.
(2)	High	Requires onsite technician for startup.
(3)	Moderate	Requires some pre-job training for workers.
(4)	Low	Requires some pre-job training of foreman.
(5)	Very Low	Intuitive; no training required.

Volume of Debris

(1)	Very High	Greater than 49 kg/m^2 (10 lb/ft^2)
(2)	High	Greater than 24.4 kg/m^2 (5 lb/ft^2)
(3)	Moderate	Greater than 5 kg/m^2 (1 lb/ft^2)
(4)	Low	Greater than 1.22 kg/m^2 (4 oz/ft^2)
(5)	Very Low	Less than 1.22 kg/m^2 (4 oz/ft^2)

A typical jobsite in the highway industry would prepare approximately 232 m^2 (2500 ft^2) with four blasters: 58 m^2 (625 ft^2) each. A jobsite assumes enough equipment and/or manpower to have similar daily production rates.

Table 82. Evaluation of surface preparation methods.

	Abrasive Blasting w/ steel grit	Abrasive Blasting w/ mineral sands	Abrasive Blasting w/ slags or silica sands	Hand Power Tools w/vac attachment to bare metal	Vacuum Blasting	Chemical Stripping
Lead Release per worker per jobsite	4 - 5 (A) 4 (A)	4 - 5 4	4 - 5 4	5 4 (B)	5 4 - 5 (B)	5 4 - 5 (B)
Lead Exposure to workers: Production worker Support Personnel Inspectors	1 2 - 4 (C) 4	1 2 - 4 (C) 4	1 2 - 4 (C) 4	4 4 - 5 5	4 4 - 5 5	4 4 - 5 5
Productivity: Production per worker	1	1	1	4 - 5	4 - 5	1 (C)
Containment Requirements	2 min	2 min	2 min	3 - 4	4	4 - 1
Fatigue Factor	4	4	4	1 - 2	1 - 2	4
Operator Skill Level	3	4	4	4	4	3
Volume of Debris	4	3	1 - 2	5	5 - 4	4

(A) These values assume very good containments typical of SSPC Class 1 or 2.

(B) This value is predicted. Testing to date has not been performed on a crew size capable of 232 m^2 (2500 ft^2) per day. Minimal containments are assumed.

(C) Productivity is based on actual time spent working. Very carefully planned and flexible working schedules would be necessary to maintain the rate since drying time of chemical stripping is very weather-dependent. Application rates will be slower on structures that are open to traffic. Multiple coats may be necessary to avoid problems caused by vibration of the structure.

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