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SURFACE PREPARATION AND COATINGS
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MARINE INDUSTRY STANDARDS
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INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

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NSRP 0509
N3-94-1

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Methods to Control Hazardous Airborne Dust

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Halter Marine, Inc.

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METHODS TO CONTROL HAZARDOUS AIRBORNE DUST

Prepared by

DynCorp
Environmental Health and Safety Services
Reston, VA

For

Peterson Builders, Inc.
April 1998

EXECUTIVE SUMMARY FOR NSRP PROJECT 3-94-1 FINAL REPORT:

METHODS TO CONTROL HAZARDOUS AIRBORNE DUST

This project was conducted to provide information to shipyards on the most effective methods to control exposure to airborne dust during surface preparation and coating activities involving potentially hazardous materials in the marine industry.

The characterization of hazardous airborne dust exposures was initiated in the following sequence:

1. A technical literature review,
2. The compilation of data from a questionnaire sent to shipyards, and
3. The proceedings of a Conference with shipyard representatives to discuss the problem of hazardous airborne emissions and promising control technology.

The combined work groups at the Shipyard Industry Conference held in August, 1995, selected the following areas for further evaluation:

1. Ultra High Pressure Water Jetting (HPWJ)
2. Low Volume Water Slurry Blasting (LVWS)
3. Vacuum Assisted Blasting (VAB)
4. Hand and Powered Tool Cleaning for Small Area Touch-up and Repair (SATR)
5. Containment with the use of Recyclable Metallic Media (CRMM)
6. Open Air Abrasive Blasting (OAAB)
7. Type CE Continuous Flow Abrasive Blast Helmets (CFABH)

This short list was derived from a much larger range of dust control options. The workshop participants identified these selections as the dust control options with the greatest potential for immediate and effective implementation.

The six engineering controls above were all evaluated with both the acquisition of field and literature data except VAB, which was evaluated with literature data only. Bath Iron Works, Puget Sound Naval Shipyard, and Newport News Shipbuilding made significant contributions to the data compiled for this report. The reported data from these yards were used to begin development of a Hazardous Airborne Dust Database (HADD). Four other yards were selected and visited to demonstrate engineering control methods. These included: Atlantic Marine, Deyten's Shipyard, Mann's Harbor, and Bangor Naval Submarine Base.

Method evaluations were conducted in two ways. First, historical air sampling data collected during use of the six selected engineering control methods were collected from participating shipyards and compiled into a Microsoft ACCESS™ database. Second, yards using one or more methods were visited by the project team members. The primary deliverables for these project efforts are:

1. A standardized reporting method for dust exposures - HADD ACCESS™ database
2. A ranked method selection list for application of engineering controls
3. An assessment of the impact of these methods on yard costs for surface preparation and coating work.

A total of 2,478 air sample entries for 39 contaminant types were collected from the shipyards and entered into the HADD. Data entry was subject to quality control audit and processed to design custom queries and graphic displays. A printout of the complete HADD data entry screen, identifying all key data elements chosen for this study, is presented. Graphs illustrating the range of airborne sample results for each contaminant are also presented.

For the methods evaluated, the highest average concentration of airborne lead, as expected, is generated from dry abrasive blasting methods such as OAAB or CRMM. The wet methods, HPWJ and LVWS, typically generated airborne lead levels below the PEL.

Similar comparisons have been made to show the average airborne concentration of airborne cadmium found during the use of these same engineering controls.

HPWJ, LVWS, and VAB methods show few instances of exceeding the PEL, but this should be viewed with caution due to the fact that there is a relatively small amount of data points available for these methods. This may be due to the localized and specialized use of these methods. More data is needed to determine how well these methods limit the exposure to below a given PEL in broader use.

A model for the economic analysis of engineering control implementation was developed to help shipyards determine the most cost-effective method of dust control. Our example applied to the model compares the cost to implement CRMM with that to implement OAAB. The comparative costs were computed in dollars per square foot of cleaning.

This comparison of dry abrasive blasting methods indicates that CRMM is most effective as an engineering control when there is a need to handle hazardous waste materials.

Next, an overall comparative assessment of dust control methods was conducted through a ranking of the selected methods against critical performance or productivity factors.

The selected methods were ranked by their effectiveness to remove coatings ability control emissions.

1 - OAAB - Most productive and best quality surface, but produces unacceptable amounts of uncontained dust and debris. Also generates very large amounts of waste which requires specialized disposal

2. CRMM - High productivity with highest quality surface achievable, reduces waste by recycling, reduces dust hazard, requires significant capital expenditure and results in relatively high cost per square foot.

3. SATR - Reduces dust and waste, but at greatly reduced production rate and decreased surface quality, cost relatively high per square foot.

4. LVWS - Greatly reduced waste and dust with a slight decrease in productivity, relatively high volume of waste requiring disposal.

5. HPWJ - Greatly reduced waste and dust, relatively high productivity and low cost per square foot, but gives reduced surface quality.

6. VAB - Reduced dust and waste, high surface quality, significant reduction in production rate and increase in cost per square foot.

Upon review of the findings from the Technology Evaluation phase of this study, the following recommendations are provided for future follow up action:

1. Shipyards should implement a consistent data collection program, integrating health and safety data with process control and productivity information.
2. Continue to evaluate specialized dust control systems designed to meet specific shipyard needs.
3. Continue to collect and compile data and facilitate exchange of information on the use of dust control methods in shipyard surface preparation.

ABSTRACT

NATIONAL SHIPBUILDING RESEARCH PROGRAM

SP-3
SURFACE PREPARATION & COATINGS PANEL

ABSTRACT 3-94-1

METHODS TO CONTROL HAZARDOUS AIRBORNE DUST

OBJECTIVE

Develop methods of maintaining employee exposure to hazardous airborne dust below the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) by means of engineering controls such as ventilation, tool designs, and production process changes.

BACKGROUND

Many of the metal materials, such as various steels and metal-containing coatings, used in the construction of ships contain lead, cadmium, nickel, chromates, and other hazardous metallic substances. Employees working with these materials can be exposed to concentrations in excess of the PELs during abrasive blasting and grinding operations.

OSHA regulations mandate that employees who work in atmospheres where they are exposed to airborne contaminants in excess of the PELs must be protected by one or more of the methods described below:

Engineering controls: The most effective, reliable, and often the least expensive long-term method of controlling exposures to airborne contaminants is to engineer out the exposure. Substituting a less hazardous material, where possible, is often the simplest and most reliable of the engineering controls. Other engineering controls include ventilation systems designed to capture the airborne contaminants and redesigning tools or processes so that fewer contaminants are generated.

Administrative controls: Since most of OSHA's PELs are based on an average exposure measured over an eight-hour shift, it is possible to lower an employee's exposure by rotating employees between the job that produces the high exposures and jobs that produce little or no exposure. This method is not allowed by **OSHA** when the contaminant is classified as a carcinogen. Other administrative controls include modifications to the employees work practices.

Personal protective equipment (PPE): The least effective and often the most expensive method of controlling exposures to airborne contaminants is the use of PPE such as respirators.

Good industrial hygiene practice as well as OSHA regulations mandate that exposures to toxic airborne contaminants must be reduced to the lowest levels possible by engineering controls. If it is not possible to achieve the PEL by engineering controls, then administrative controls must be used to further reduce exposures. If these means are not adequate to reduce exposures below the PEL, then the use of PPE must be implemented.

When exposures to lead and cadmium exceed the PEL, OSHA regulations mandate that employers implement a number of additional controls in order to assure the safety of the employees. These controls include special training, medical surveillance, and special hygiene facilities and practices. "Regulated areas" must be established to isolate operations that produce hazardous levels of airborne contaminants.

These controls can cost thousands of dollars per exposed employee per year and production efficiencies can be reduced by 30% or more due to the encumbrances of the PPE, regulated areas, and hygiene practices. This reduction in efficiency has the potential of causing significant schedule impact. Therefore, it is sensible, not only from a health perspective, but also from a business perspective, to engineer operations so that employees will not be exposed to concentrations that exceed the PEL.

TECHNICAL APPROACH

Because of the variety of coatings and coating removal operations present at different yards, it will be beneficial for a number of yards to participate in this project. Each yard should identify methods used to control exposures to hazardous airborne materials during coating removal operations. A lead yard will be identified and will provide a project manager who will coordinate the activities of other participating yards, administer project funding, gather information from participating yards, and write a final project report. The lead yard on the project will determine the scope of the problem by surveying other shipyards. This will be accomplished by sending questionnaires to a large number of yards. Yards who respond to the questionnaires and indicate that they have recognized the problems will be invited to participate in a small conference designed to fully scope the problem. The conference will be held at a location central to the participating yards.

At this conference, the participating yards will identify which yards will participate in identification and evaluation of new control methods. A standardized method of testing, evaluation, and reporting will be established. It is anticipated that three yards will participate in testing and evaluation.

Each yard participating in the testing and evaluation will assemble a team comprised of managers and mechanics from departments such as Paint Shop, Temporary Ventilation, Industrial Hygiene, Small Tools, Production Engineering, and Production Management. These teams will brainstorm ideas for controlling airborne contaminants generated from blasting, grinding and other operations that generate large concentrations of airborne dust. Such ideas should, at least, focus on ventilation design, tool design, production process modifications, work practices, and coating substitutions.

Because the teams will be brainstorming new control methods, it is not possible to determine how many new methods will be evaluated or what equipment will need to be rented, purchased, or developed for each method proposed. However, each team should have a goal to evaluate at least one new control technology per month. Procurement of new equipment is likely for each new method tried.

ESTIMATE: TIME/COST

The lead yard will be responsible for administering all funds. It is intended that funding will be evenly distributed among three yards participating in testing and evaluation.

TOTAL PROJECT COST- $260,000.00

PROJECT DURATION: Not more than 24 months

BENEFITS

It is obvious that reducing exposures below the PEL by engineering controls will have the greatest benefit to employee health and safety. Implementing engineering controls that reduce exposures below the PEL, could increase in coating removal production efficiency by as much 33% by reducing procedures that are required when exposures are above the PEL. This project will also assure compliance with OSHA regulations. It is difficult to predict what other cost benefits may result. Other areas of savings could be reduced power costs due to the use of more efficient ventilation equipment, and savings due to more efficient production methods.

DELIVERABLES

I - Drawings and specifications, prototype, and demonstration of all tools and equipment developed for the project.

2. A report comparing the equipment, performance, and production efficiency ratings will be provided.

Introduction and Background

This project was conducted to provide information to shipyards on the most cost effective means to comply with OSHA regulations governing control of airborne dust in operations in the marine industry, (specifically 1915 and in part 1926.62), while conducting surface preparation or coating activities involving potentially hazardous materials. The technical approach taken to complete the study is summarized below:

Need for Study

Coating removal commonly results in the formation of airborne dusts and particulate matter. This occurs because most coating removal processes impart energy to the surface, which breaks the coating film into small pieces. This holds true for coating removal processes in all industries; the shipbuilding industry is not unique in this regard.

Coating removal on board ships using traditional methods (power tool cleaning or abrasive blasting), can result in generation of dusts containing significant quantities of lead, cadmium, nickel, chromates, and other hazardous metal substances. Other industry sectors face similar problems of heavy metal containing paint materials, but the shipbuilding industry is probably unique in the range of existing surface coatings that contain such problematic heavy metals.

Until very recently most of the marine coatings specified for use on Navy ships could contain one of several heavy metal products with chromium, lead, barium, strontium and tin being common constituents. Moreover, the base metals from which coatings are removed may also have a significant heavy metal concentration, and metal filings or debris may be derived from the base metal during grinding or abrasive blasting. Finally some of the abrasive media used in coating removal have levels of heavy metals. Even if a low limit is set on heavy metal content for abrasive media, a combination of operating circumstances could create conditions where the airborne concentration of heavy metals exceeds statutory limits.

Marine coating removal is made more complex on three counts:

- Much coating removal takes place in small, "confined" spaces, e.g., bilge tanks or staterooms, where dust concentrations can mount.

- Most coating removal is conducted within the confines of a shipyard, considered a fixed facility, and to which the most severe PELs apply.

- Because a shipyard is a fixed facility, it is subject to a rigorous imposition of the CERCLA rules regarding reportable quantities of hazardous materials, thus there is a driving force to collect and account for waste materials. This may in turn force the use of containments for paint removal, increasing the resident airborne concentration of heavy metals in the working area.

In summary, though new coating materials do not generally contain heavy metals, a significant proportion of both Navy and commercial fleets have old heavy metal containing coatings on their metal surfaces. Because of the importance of repair jobs to US shipyards, it is critical that methods of removal be identified which minimize worker exposure to heavy metals.

Controlling Worker Exposures

When it is known that employees are working in atmospheres that expose them to airborne contaminants in excess of the PELs, OSHA regulations dictate that one of the three classes of control measures shown below be taken.

Engineering Controls

OSHA would prefer that all efforts to control airborne contaminant exposure begin with engineering controls because they can permanently reduce the level of exposure to a worker. For a control measure to be designated an "engineering control" it must change the workplace, the work method, or the materials used to conduct the work. For instance, if the abrasive media contains heavy metals, one engineering control would be to use a medium free of heavy metal compounds. An example of a changed work method might be the use of a chemical stripper in place of abrasive media. A change to the work place could be the installation of improved ventilation or dust collection. Engineering controls can have high up-front costs due to capital expenditures, but often result in the reduced overall costs due to the permanent elimination of a hazard.

Administrative Controls

A control measure is designated an administrative control if it changes the time at which a work action takes place, or the duration of that action. Most PELs are based on an eight hour work day, thus if an employee's work schedule is adjusted so that only half the day is worked in the atmosphere with contaminants, his net exposure may be kept well below the PEL. For most practical purposes, administrative controls are of limited use in a marine setting. This is because the dusts created by coating removal are likely to contain a mixture of materials such as cadmium or hexavalent chromates that are considered carcinogenic. OSHA does not permit the use of administrative controls when the contaminant present is carcinogenic. Administrative controls can add a large overhead burden to managing a complex operation such as a shipyard.

Personal Protective Equipment (PPE)

This is the control measure most familiar to shipyard workers at the deckplate level. In almost all cases, coating removal is carried out with the use of some type of personal protective equipment. Unfortunately, PPEs are a recurrent expense. Moreover PPEs will often reduce the productivity of a worker. Thus PPEs add to a shipyards operating costs, both in terms of increased costs per unit of work, and in terms of maintaining an inventory of PPE items. Achieving a working environment in which PPE measures are not required would be an ideal outcome, but practically speaking, this is unlikely.

Ideal Control Methodology

The ideal control method is an engineering control because it can change the work process so as to minimize worker exposure. Typically, if exposure to a hazardous material can be controlled by engineering the work process or equipment to eliminate or reduce exposure below the PEL, then no further action need be taken (unless of course, the material constitutes a long term health risk, such as a carcinogen). Due to practical constraints, however, administrative controls and Personal Protective Equipment remain widely used.

Many forms of engineering control measures are currently in place to combat exposure to hazardous materials. In the case of surface preparation and painting, a typical example would be the presence of walk-in blasting and painting rooms with controlled ventilation. Though these facilities represent a significant investment for a shipyard, they have benefits that offset their cost. For example, with a walk-in blast and paint room it is possible to conduct fabrication and finishing activities throughout the year, with little interference from the weather.

An optimum approach to dealing with hazardous airborne dusts is a set of engineering controls that has the same beneficial impact of a blast and paint room while controlling worker exposures.

Typical Control Methodology

Conducting surface preparation and coating repair work involves a complicated set of activities that require rapid response from a shipyard. It is not surprising that an ideal method for controlling worker exposure has not been devised for every instance. As a result there remain many examples in which a yard worker must resort to the use of PPEs to limit exposure to a hazardous substance. The most common type of PPE employed by a paint department worker is a respirator.

The use of respirators can lead to several types of productivity or quality problems. For example:

- Operators often report that the PPE makes the work more tiring. The net result is lower productivity or shorter peak productivity.

- Operators must take time away from productive work for the necessary functions of maintaining or replacing parts of the respirator. The net result is lost productive work time.

- For abrasive blasters, the PPE of choice is a visor fitted air supplied respirator. This type of equipment is often difficult to see through, which results in either a reduction in quality of work or repeated work to bring the finished item up to quality.

Finally, respirators are a consumable. That is, they must be maintained in inventory and are a recurrent cost to a shipyard.

Economic Impact of Control Methodology

Any factor that reduces the rate of production increases the cost of the article being produced. In this light, control methods for reducing exposures below PELs are no different from other practices. The cost impact of OSHA mandated controls is most severe when the material of concern is a carcinogen such as lead or cadmium. Both of these metals are encountered in shipyard production work.

In this worst case, not only must the best engineering controls be used, but it is critical that, if the PEL is still exceeded, a program of training, medical surveillance, and hygiene practices be in place. Under these circumstances, the work area can only be used by those who are participants in the program. This consequence is costly on several counts: first it imposes a significant overhead burden on the yard management; second, the productivity from the facility may be reduced if PPE is in use; third, because the facility restricted use, it cannot be employed by the yard in a flexible manner. It is estimated that the cost to yard productivity from such regulated work practices is upwards of 30%.

Project Tasks and Approach

Information Gathering

A carefully designed information search was conducted to identify the occurrence, type, and frequency of problems with hazardous dust exposure from typical paint department practices such as surface preparation and coating. The relationships among surface preparation practices, coating or base metal composition, and hazardous material exposure were defined. Particular attention was given to identifying those practices that create the need for a regulated program due to PEL excursions with carcinogenic materials. Information was also gathered on engineering, administrative and personal protection control measures to combat typical hazardous airborne exposures in coating work. The information search focused on those practices being used in US shipyards. The experience of other industries in identifying and controlling hazardous airborne contaminants was also examined.

The literature search and information retrieval revealed the following as constituting the state of the art in the use of engineering, administrative, or engineering controls to mitigate hazardous airborne dusts. Availability information for the deliverables describing these information gathering activities is found in Section VIII.

Engineering Controls - General Industry

The following paragraphs summarize the findings from our surveys of general industry practice on the use of engineering controls to control hazardous airborne dusts. The operating parameters for typical engineering controls, and their components, vary widely. Users must consult with equipment suppliers to learn operating parameters for individual engineering control solutions.

- The primary engineering control to protect workers in areas outside the immediate work zone is containment coupled to high quality ventilation.

- The use of containment, along with abrasive recycling, is growing, both in general industry and shipbuilding. The use of containment with traditional media is also being examined.

- In general industry, the use of containment and abrasive recycling is still prompted by concerns about hazardous paint removal-, typical dusts are lead, chromium, and barium.

- In the shipbuilding industry, the use of containment and abrasive recycling may or may not be prompted by concerns about hazardous paint removal.

  - When abrasive recycling and containment is used in general industry it is typical for steel grit or other metallic abrasives to be used.

- •It is still typical for US Shipyards to use mineral abrasive, though some facilities are moving to use metallic abrasives exclusively.

- US shipyards face the same potentially hazardous dusts as general industry. However, reports of lead paint removal are less frequent from shipyards than from general industry.

- There is little information available on the role of PCBs in coatings as hazardous airborne contaminants.

Shipyard Specific Issues

In addition to these trends in engineering control use from general industry, there are some specific issues which arose from the shipyard visits and phone surveys.

- There is no universal abrasive recycling and containment design. Work piece and work area dimensions differ considerably from yard to yard.

- The types of containment needed in a shipyard can be divided into three general classes.- (1) Ad hoc project specific containments using flexible materials; (2) Semi permanent reusable containments for large structures using interior support structures, and; (3) Semi-permanent modular containment enclosures for small sections of a structure, compatible with existing moving equipment in the shipyard.

- Traditionally, US shipyards have used non-metallic media for surface preparation during repair. Thus, it would be ideal to identify a recycling unit which is fully compatible with non-metallic media.

- The kind of contaminants encountered in ship painting operations are similar to those encountered in general industry, and include lead, chromium, cadmium, and respirable portions of mineral abrasive dusts (PM1O fraction).

Based on the knowledge gleaned from the information gathering and shipyard surveys, the following technical areas were selected as potential topics for papers at the shipyard conference on hazardous dust exposures:

- Lead exposures
- Chromium exposures
- Zinc exposures
- PM 10 exposures
- Engineering controls
- Administrative controls
- Personal protective measures

Method Selection Workshop

The methods selection workshop was a critical and valuable activity within this project. The conference was held in Norfolk, VA in August, 1995. Over 50 persons attended, including representatives of private and government shipyards, equipment suppliers, consultants and trade research organizations. Lasting a total of three days, the outputs from the workshops were:

- A set of proceedings and technical papers
- A comprehensive plan for execution of the field evaluation phase of engineering controls
- Selection of participating shipyards for the remainder of the conference

Conference Activities

The methods selection workshop was preceded by a presentation of a Technical Program. This allowed for presentations by shipyards describing the range of generated dusts and hazardous dust control methods used in the marine industry. Several presentations were also made by industry experts and researchers on new or evolving engineering controls for hazardous dust exposure limitation. Nine papers were presented in the seminar. Following the seminar, a round-table discussion was held concerning typical shipyard hazardous dust problems from surface preparation and their mitigation. This round-table discussion helped form the focus for the problem solving group sessions, which occupied the remaining two days of the conference.

Problem Solving Group Summaries

The following is a report of the first full day of the problem solving groups. Each group went through a similar set of actions:

Defined scope of the problem

Prioritized solutions for examination

(Note- The titles of the two problem solving groups shown below differ from those in the conference program. These reflect the true focus of the group.)

Work Group A - Processes and Containment - Project Focus Area Selections

Group A examined over ten processes and approaches with potential to reduce hazardous dust exposure. They screened the candidates against five criteria to prioritize for selection. Scoring was on a -3 to +3 scale. Open air abrasive blasting was used as a benchmark against which the viability of the candidates was measured. The weighted criteria were:

- Ability to reduce dust (score x 30);

- Degree of added cost by the process (x 15);
- Ability of the process to improve competitiveness (x l5);
- Quality of work output compared to benchmark (x 30);
- Range of application of work process compared to the benchmark (x 10).

Based on these criteria, six processes were identified that could economically reduce hazardous dust exposure emissions. In a second screening two of these processes, containment and the use of metallic abrasives were eliminated because they are covered under a companion project 3 -94-2, which will report results to 3 -94- 1. The remaining processes are:

- Ultra High Pressure Water Jetting (HPWJ)

- Low Volume Water Slurry Blasting (LVWS)

- Vacuum Assisted Blasting

- Hand and Power Tool Cleaning for Small Area Touch-up and Repair (SATR) (Overcoating).

The group also considered the question of material substitution, which is an alternative to engineering controls. The suggested activity was to evaluate alternate media such as garnet, aluminum oxide and sponge encapsulated abrasive within the above process evaluations using blasting with a slag abrasive as a control method.

The group also looked at the issue of Personal Protective Equipment. The suggested activities were to.-

- Review data on protection factors (PFs) for Type CE or newer abrasive blasting helmets.

- Acquire noise data for suggested dust control processes.

Finally a suggestion was given about the manner in which data is reported. If exposure data are developed, care must be taken in reporting accurately the duration of evaluated process activities. This will help clarify the presentation of time weighted average data that is extrapolated from observed activities of varying real-time durations.

Work Group B - Regulations & Process Improvement - Project Focus Area Selections

Group B examined three general areas: regulations, process control, and personal protective equipment. The consensus of the group was that in addition to looking at new methods, existing methods should be examined with a view to process optimization.

The proposals from group B were:

- Examine optimizing the blasting process to both increase production and reduce emissions.

- Include an examination of reusable abrasives coupled to uniform standards of cleaning using a total process view.
- Include an examination of PPE focused on protection factors for type CE or newer abrasive blasting hoods, using monitoring both inside and outside the-hood.

Combined Work Groups

The two groups met in a joint session to combine the best components of each others suggested courses of action. The result of this meeting was a suggested approach for data acquisition.

Suggested Approach for Data Acquisition During Evaluation Phase

One purpose of Task B was to determine the effectiveness of current technologies employed by shipyards to maintain employee exposures to hazardous airborne dust below the PELs.

The six technologies selected for field evaluation were:

- High Pressure Water Jetting (HPWJ)
- Low Volume Water Slurry Blasting (LVWS)
- Vacuum Assisted Blasting (VAB)
- Small Area Touch Up and Repair (SATR)
- Containment with use of Recyclable Metallic Media (CRMM)
- Open Air Abrasive Blasting (OAAB)

The most suitable type of personal protective equipment selected for field evaluation was the Type CE continuous flow abrasive blast helmets (CFABH).

The general operating procedure for this phase involved two steps. First there was an extensive targeted data acquisition from current and historical exposure data from participating shipyards and from other sources known to the research team. Second, there were field visits to observe and record the in use capabilities of the different methods.

Based on the problem solving sessions at the methods selection conference the following suggestions were made on what criteria to assess during method evaluations under Task B3.

Table 1: Suggested Data Acquisition for Task B3: Methods Evaluations

Method or Process	Criterion 1 - Equipment and Material Set-Up	Criterion 2 - Containment Requirements (and PPE)	Criterion 3 - Monitoring Methods and Analyses
High Pressure Water Jetting	a - Use both 25,000 PSIg and > 25,000 PSIg.	a. Obtain reports on suitable PPE protocol from participating yards.	a. Personal air monitoring for dust and, if needed, lead and chromium.
	b. Use both with and without abrasive injection	b. Monitoring of effluent (water discharge).	
		c. Take noise readings	
Low-Volume Water Slurry Blasting	a. Set-up per manufacturer	a. Obtain reports on suitable PPE protocol from participating yards.	a. Personal Air Monitoring for dust lead and chromium.
		b. Monitoring of effluent (water discharge).	
		c. Take noise readings	
Vacuum Assisted Blasting	a. Focus on newer vacuum assisted methods, such as automated blasting, or use of hull-side wheelabrators.	a. Use full-face respirator at minimum until proven safe.	a. Personal air monitoring for dust, lead and chromium.
		b. Take noise readings	
Small Area Touch-Up and Repair	a. Hand and power tool cleaning	a. Use full-face respirator at minimum until proven safe.	a. Personal air monitoring for dust, lead and chromium.
	b. Vacuum shrouded power tool cleaning		b. Take noise readings
Containment with Use of Recyclable Metallic Media	Incorporate Data from 3-94-2 Project.	Use Mini-enclosure with high rate of ventilation.	a. Personal air monitoring for dust, lead and chromium.
	Blasting helmets, minimum Type CE, preferably Lancer™.		b. Take noise readings
	c. Visible emissions monitoring only, high volume sampling suggested.		
Open Air Abrasive Blasting	Use standard practices from yard	Blasting helmets, minimum Type CE, preferably Lancer™.	a. Personal air monitoring for dust, lead and chromium.
Incorporate use of Schmidt ™ abrasive metering valves.			b. Take noise readings
Incorporate use of alternative media, garnet and, attempt optimization of abrasive use.			c. Visible emissions only.

Results and Discussion

This section focuses on the analysis of results from the data acquisition and field evaluation tests of the six engineering controls and one PPE measure selected during the methods selection workshops described earlier in Section 2B of this report. This workshop provided a general work plan which was used as the basis for data acquisition and field evaluation efforts. The results reported earlier from the field evaluations are updated to reflect the new data from this evaluation of the use of containment, as well as data on a common PPE measure, use of a Type CE blasting helmet.

TYPES AND SOURCES OF DATA SOUGHT

Methods and Measures Evaluated

The engineering controls evaluated via data acquisition and field visits were:

- Ultra High Pressure Water Jetting (HPWJ) - Both field and literature data were acquired.
- Low Volume Water Slurry Blasting (LVWS) - Both field and data reports were acquired.
- Vacuum Assisted Blasting (VAB) - Only literature data were acquired.
- Small Area Touch Up and Repair (SATR) - Both field and data reports were acquired.
- Containment with Use of Recyclable Metallic Media (CRN" - Both field and data
- reports were acquired.
- Open Air Abrasive Blasting (OAAB) - Both field and data reports were acquired.

Participating Yard Selection

The yards agreeing to provide data were:

- Bath Iron Works
- Puget Sound Naval Shipyard
- Newport News Shipbuilding

The reported data from these yards were used to begin development of a Hazardous Airborne Dusts Database, HADD.

In addition, several other yards were contacted for their willingness to demonstrate engineering control methods used during the field phase. Visits were scheduled to these yards to observe individual engineering controls in use. These yards included:

- Atlantic Marine
- Deyten's Shipyard
- Mann's Harbor
- Bangor Naval Submarine Base

Several site visits were also made to Newport News Shipbuilding. These site visits did not include field observation of surface preparation work.

Method Evaluations

Method evaluations were conducted in two ways. First, new and historical data for use of the six selected engineering control methods were collected. These results were compiled into a Microsoft ACCESS™ database. (All of the data from this data acquisition are included in the report on Tasks B 4 and B5 submitted as an Appendix to this report.) Second, yards using one or more of these methods were visited by the project team members. The data acquisition efforts were greatly assisted by the participating yards.

The primary deliverables from these project efforts are:

- A standardized reporting method for dust exposures - using the HADD ACCESS™ Database
- A ranked method selection list for engineering controls
- An assessment of the impact of these methods on yard costs for surface preparation and coating work

COLLECTION OF DATA

In an effort to provide the most comprehensive collection of air sample data, the participating shipyards defined key variables required to compile a thorough historic profile for each target method. Since each shipyard had a different air sample data collection form, it was necessary to generate one generic Air Sample Data Entry Form into which all pertinent data collected could be entered. A total of 22 specific entry elements were identified on the Air Sample Data Entry Form as significant performance criteria.

To efficiently manage the sample data, a customized electronic data entry version of the Air Sample Data Entry Form was developed using Microsoft ACCESS™. The decision to use ACCESS™ software allowed the grouping of all information gathered into a central Hazardous Airborne Dust Database (HADD) and provided a wide variety of options for working with the data including custom queries and graphing. The electronic Air Sample Data Entry Form was developed to include drop down windows for many of the elements in order to provide both speed and consistency in the data entry process. An example of the Air Sample Data Entry Form is presented below in Figure 1, below.

Once the means of data tabulation were established, the gathering of air sampling data from participating shipyards started. The air sampling data were collected through a combination of on-site work, electronic transfer, and manual retrieval.

Figure 1: Typical Data Entry Form from the Hazardous Airborne Dust Database (HADD)

HADD Data Collection

Entry Number: ________________ **Today's Date:** ________________

Method: ________________ **Site:** ________________________

Abrasive Type Recorded: ☐ **Compressor Air Pressure:** ☐

Nozzle Air Pressure Recorded: ☐ **Mesh Mix Recorded:** ☐

Abrasive Metering Method Recorded: ☐ **Nozzle Diameter Recorded:** ☐

Gauge Check of Nozzle Recorded: ☐ **Containment Square Footage Recorded:** ☐

Number of Workers: __________ **Dust Collector Make/Model Recorded:** ☐

PPE Make/Model Recorded: _______ **Coating Content (Pb):** ______________

Work Duration: __________________ **Productivity:** ____________________

Test Method: ____

Results (ug/m3): _____________ **Sample Date:** _______________

Comments: ____

____

____

After the target engineering control method for the field evaluations were identified, Navy and Commercial shipyards around the US were contacted in an effort to determine locations where the various methods were in operation and could be observed. Manufacturers of related process equipment were also contacted to determine which shipyards were using the equipment. The list developed to track shipyards using different types of equipment needed for each engineering control is included in Section "Supplementary Materials."

Site visits were made to shipyards in Virginia, North Carolina, South Carolina, and Washington. Processes observed included the following: Open Air Abrasive Blasting, (OAAB), High Pressure Water Jetting, (HPWJ), Low Volume Water Slurry Blasting (LVWS), and (SATR). Historical air monitoring data was provided by participating shipyards for these methods, allowing evaluation for this study. On-site work included filling out a detailed observation questionnaire, photographing of the process(as permitted by security restrictions), and assessing the quality of the surface finish by comparison against industry standards. In addition, through a collaborative effort with NSRP Project 3-94-2, field data on Containment with Use of Recyclable Metallic Media (CRMM) is included from work at Atlantic Marine in Jacksonville, Florida. Field monitoring for respirable dust was conducted during the evaluation of the CRMM unit. The research team was not able to observe the Vacuum Abrasive Blasting (VAB) method at a shipyard due to its unavailability during scheduled visits.

Figure 2 Ultra High Pressure Water Jetting (UHPWJ) equipment in dry dock.

Figure 3:Workers on Hi-Lift using UHPWJ to remove paint from hull.

Figure 4:UHPWJ pump.

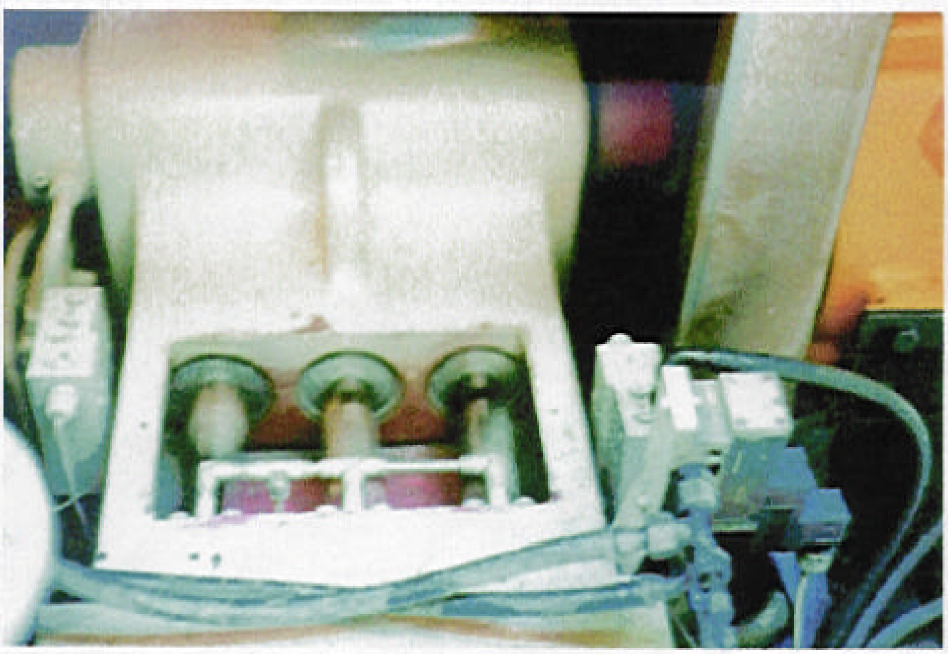


Figure 5: Diesel engine power source for UHPWJ.

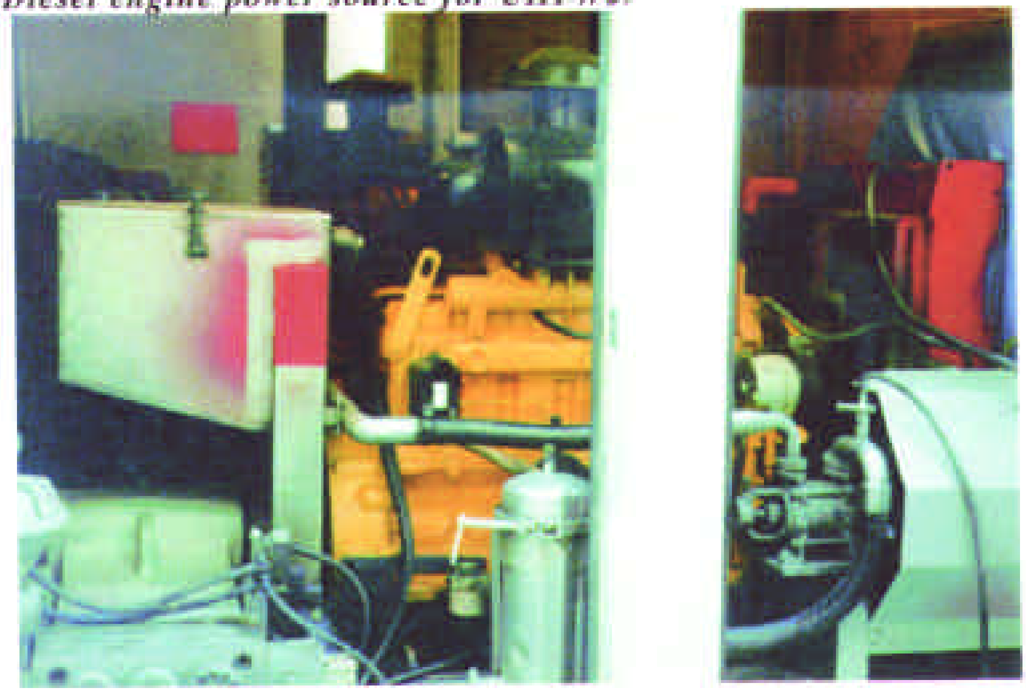


Figure 6: Nozzles for UHPWJ.

Figure 7:Coating removal on hull using UHPWJ.

Figure 8:Operator and helper using UHPWJ

Figure 9: Comparison of coated area and area cleaned with UHPWJ.

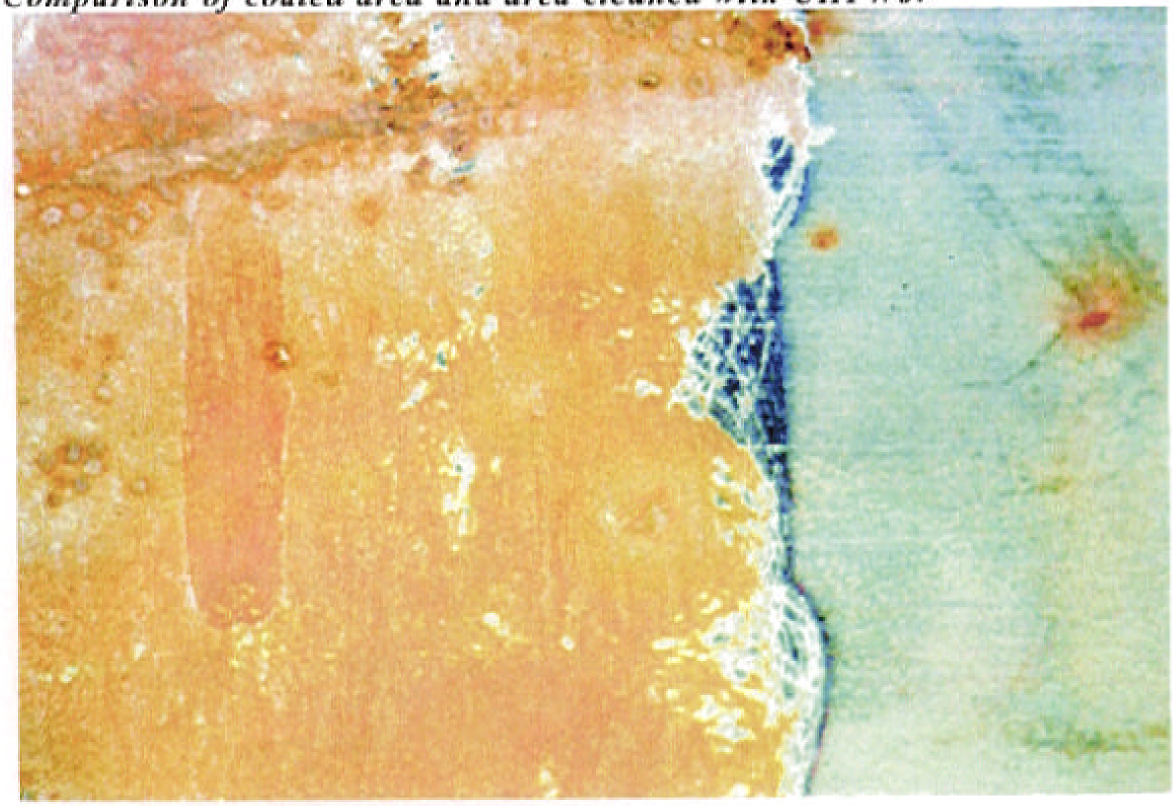


Figure 10: Workers removing coating on hull using UHPWJ.

Figure 11: Worker using UHPWJ to remove paint from grating.

Photographs taken during the site visits are presented in figures on the preceding pages. Information regarding each engineering control method observed was recorded on field evaluation forms and is presented below, followed by descriptions of process capabilities.

Ultra High Pressure Water Jetting (HPWJ)

The Deyten's Shipyard site in South Carolina was visited. The purpose of the visit was to observe Deyten's ultra high pressure water jetting (HPWJ) operation. Deyten's was using ultra HPWJ to completely remove the surface coating from the submersible half of two tugs and one L.C.U. during the site visit. The ultra HPWJ was also used for spot removal of coatings as needed.

The typical pressure used in this ultra HPWJ operation was 25,000 to 30,000 PSIg at the compressor. Water pressure was monitored at the compressor's gauges; it was not recorded at the nozzle.

The nozzle was labeled with a manufacturer's specific code of E09. (The internal diameter, ID of eight independent jet orifices in the nozzle can range between 0.2 mm and 1.2 mm. The ID is varied to control output pressure. With typical settings of 5.3 gpm, to maintain 30,000 PSIg, ID is operator set to 0. 35 mm). There are no common codes for ultra HPWJ equipment nozzles, as is typical for abrasive blast nozzles. The operator usually inspected the nozzles for wear and deterioration. Nozzle diameter was not measured or recorded, and nozzles were replaced at the operator's discretion.

Operators conducted ultra HPWJ at both the ground level and on the ship's hull from powered lift baskets. At the time of the visit there were three lift baskets working on the front two ships and one worker water blasting at ground level. The blasters working from the lifts baskets typically had a helper in the basket to help control the hoses.

In areas where the coating had been removed, there was a considerable amount of flash rusting observed. Prior to paint application, the surface was reblasted to remove visible flash rusting. There are no industry standards available to determine acceptable levels of flash rusting. The acceptance of the surface for coating depends on the type of coating being applied.

Containment was not used. The water suppressed all visible dust. Personnel at Deyten state that ultra HPWJ suppresses all dust (hazardous emissions) that is generated from coating removal operations, so worker exposure to airborne concentrations of hazardous metals is minimal (a contention that is supported by analysis of the HADD data). The dry dock itself was used as the containment for water and debris generated from the blasting operation. Water and debris were scheduled to be collected upon completion of the project.

Estimated productivity at the time of the site visit varied from 95 to 125 square feet per hour. The yard had not, up to this point, completed any separate measure of worker productivity using this method.

Deyten's Shipyard also uses a semi-automated ultra HPWJ head manufactured by WOMA Corporation. Although it was not in operation at the time of the site visit, areas on the ship's hull where it had been used were identified and observed. The productivity rate for this piece of equipment was estimated at 450 to 510 square feet per hour. As with the single head blast unit, productivity measurements had not been taken.

Coatings removed from the three vessels contained no hazardous metals. Shipyard air monitoring results were not available for review.

The items of personal protective equipment used by the blasters were:

- Poly coated full body suits
- Synthetic/rubber gloves and boots
- Full face shields
- Hard hats
- Hearing protection - ear muffs and ear plugs

Records of noise level readings were not available for review. The estimated noise level experienced by the operator from this operation was 95 to 100 decibels. The OSHA PEL for noise exposure is 90 dBA as an eight hour time weighted average (TWA).

Figure 12: Spot removal by needle gun prior to complete section removal and replacement.

Figure 13: Needle gun being used by a work release program inmate inside storage tank.

Figure 14:Needle gun in use cleaning primer coating and welding slag.

Figure 15:Needle gun used during SATR operations.

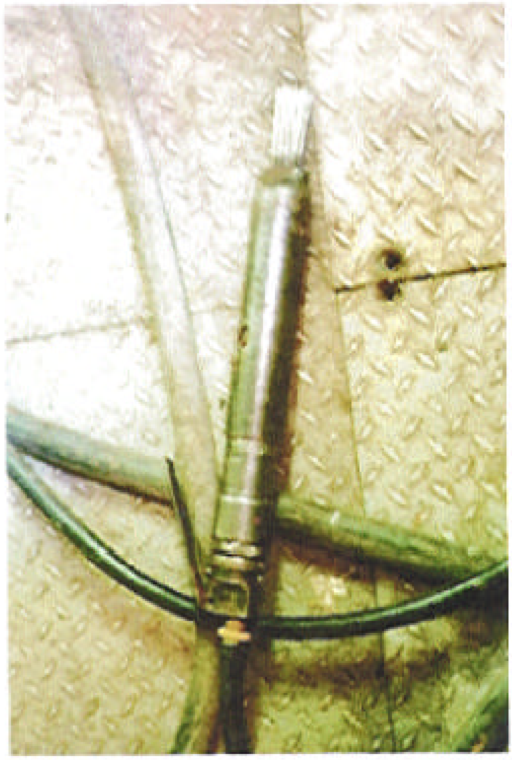


Figure 16:OAAB operator on Hi-Lift removing hull coating.

Figure 17:Type CE Abrasive Blast Helmet in use during OAAB.

Figure 18:OAAB operator on Hi-Lift removing hull coating.

Figure 19:Air supply manifold for Type CE Abrasive Blast Helmet

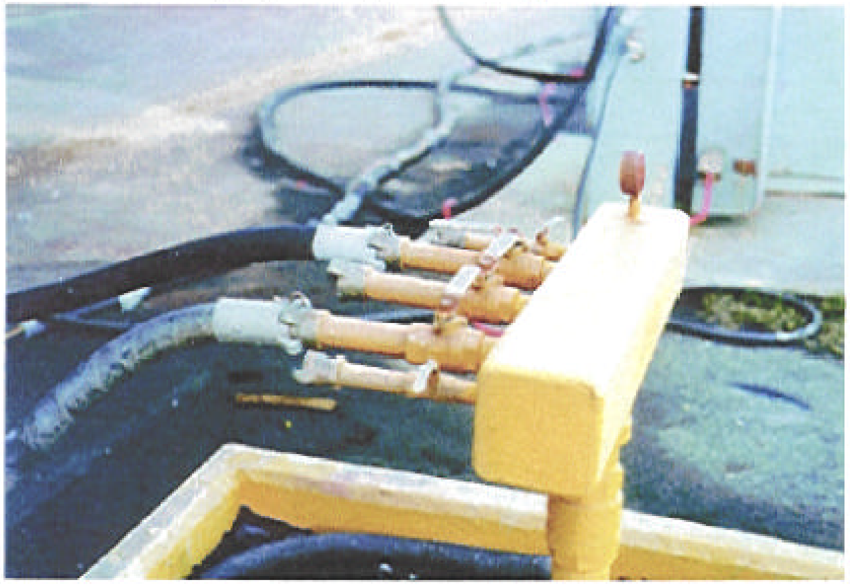


Figure 20:OAAB equipment on dock

Figure 21:OAAB blasting pot filled with coal slag media.

Figure 22:Air Source for supplied air Type CE Abrasive Blast Helmets.

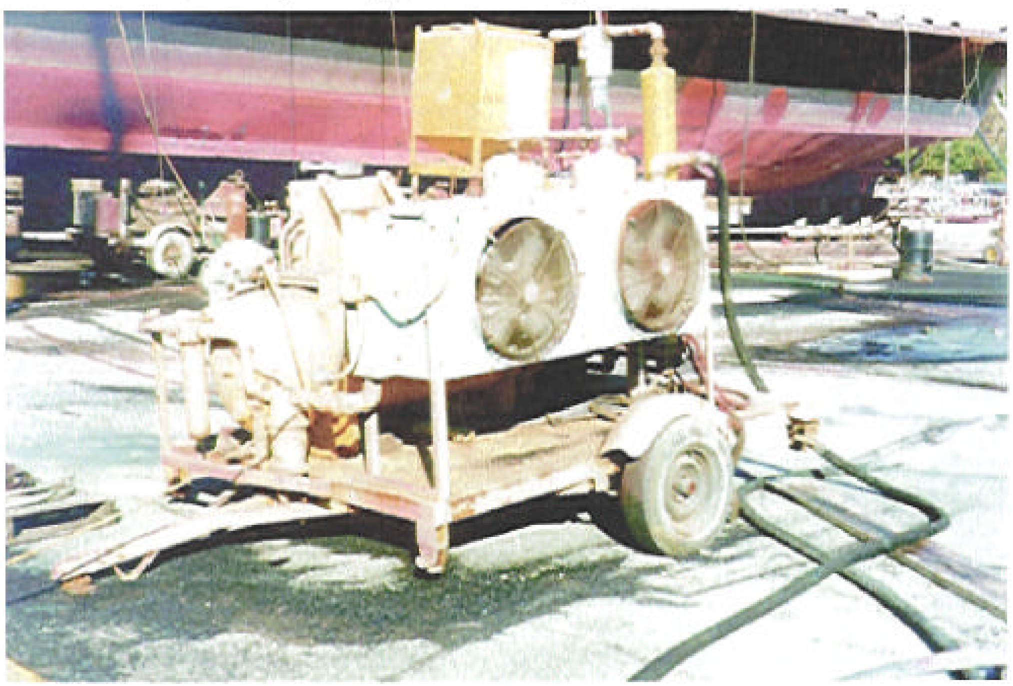


Figure 23:Ship having hull coating removed by Open air Abrasive Blasting (OAAB) and Small Area Touchup and Repair (SATR).

Small Area Touch-Up and Repair (SATR)

The North Carolina Department of Transportation Ferry Division at Mann's Harbor site was visited. The purpose of the visit was to observe small area touchup and repair (SATR) using powered hand tools and open air abrasive blasting (OAAB) operations.

At the time of the site visit, one large ferry was in dry dock for complete coating removal and repainting of the hull. The shipyard typically only works on one ship at a time. Mann's Harbor was operating on one eight hour work shift, five days per week.

The SATR method observed for coating removals at Mann's Harbor was the use of unshrouded needle guns. Three workers were observed removing coatings from pipes and floor areas from the ships interior in cramped work areas. Two workers were observed removing coatings from small areas on the ship's exterior (i.e. substrates prior to welding and cutting).

The items of personal protective equipment used by the workers during SATR were:

- Full body cotton suits
- Abrasion resistant gloves
- Steel-toed safety shoes
- Hard hats
- Full face respirators with HEPA filter cartridges

Mann's Harbor recently changed from half-face respirators to full face respirators to increase worker's eye and face protection. Personal air samples were not collected.

Noise levels generated by needle gunning the interior surfaces of the ship were extremely high. Readings were not available from the yard. All workers wore ear muffs for hearing protection. The noise level for needle gun work inside the ship was estimated at 95 decibels.

Needle guns were operated from the same air source as abrasive blasting. The air pressure at the compressor was approximately 120 PSI. Air pressure for the needle guns was monitored by visual inspection of the pressure gauges, but was not recorded.

Productivity for coating removal using needle guns had not been measured at Mann's Harbor and no estimate was given.

Interior needle gun work observed consisted of coatings removal from around pipes and the surrounding floor areas. In one area, workers were preparing to needle gun inside storage tanks used for sanitary wastes (sewage).

Open Air Abrasive Blasting (OAAB)

OAAB was also observed during the visit to Mann's Harbor. OAAB was performed on the hull and on small parts located away from the ship. Hull blasting was performed from a powered lift basket. Blasting of small parts was conducted in an area located away from the main yard, along the outer perimeter of the yard. Typically, either one or two employees performed blast operations for 4 to 8 hours per shift.

The shipyard had not measured productivity, but during the site visit productivity was estimated at 80 square feet per hour. The blast media was coal slag, which is the only abrasive media used in the shipyard. Mesh mix of the material was not determined.

The air pressure at the compressor was 120 PSI. Air pressure for abrasive blasting was monitored by visual inspection of the pressure gauges on an occasional basis, but was not recorded.

The blast nozzle size was a #8 (0.5 in. diameter). Nozzle air pressure, size, and diameter were not recorded by the shipyard. The operators changed the nozzles at their discretion.

The shipyard did not use containment or dust collection methods. Prevailing winds moveddusts generated by the process away from the work zone. Blast operators tried to maximize natural ventilation by positioning themselves with their backs to the wind. Spent debris collected on the ground and did not appear to be picked up with any frequency.

Flash rusting did occur following the OAAB. The surface was lightly reblasted prior to painting.

The items used by the workers during OAAB were:

- Full body cotton suits
- Abrasion resistant gloves
- Steel-toed safety shoes

• Type CE abrasive blast helmets

• Hearing protection

• Personal fall protection

Workers were observed to wear Bullard Type CE abrasive blast helmets during blast operations on the outside of the ships hull. The coatings on the vessel were reported to contain no hazardous materials. Personal air sampling results were not available for review.

Low Volume Water Slurry Blasting (LVWS)

Bangor Naval Submarine Base located near Silverdale, Washington was visited. The purpose of the visit was to observe Bangor's Low Volume Water Slurry (LVWS) blasting operation. The Bangor Shipyard performs work on Trident Submarines. Due to security concerns, photography was conducted by a Bangor NSB Engineer in accordance with site permits and procedures.

The shipyard reported that the LVWS blasting had provided the best results of all coating removal methods tried in the dock.

Air pressure was monitored at both the compressor and at the nozzle. The typical compressor air pressure used for this operation was between 100 and 110 PSI. The water pressure at the nozzle was approximately 3,000 PSI. The blast nozzle delivered 80% abrasive and 20% water. Water usage was approximately 16 to 18 gallons per hour. During the site observation, a #8 nozzle was used and the nozzle pressure was recorded at 80 PSI with 50 -100 feet of hose.

The blast media used was a premix of 78% mesh copper slag, 20% cementitious silicate additive (Blastox), and 2% rust inhibitor. Other blast media used by the shipyard include: Garnet, glass, and Potlife with Blastox.

The items of PPE used by the workers during the LVWS blasting were:

• Rubber rain suits

• Hard hats

• Gloves

• Boots

• Full face respirators

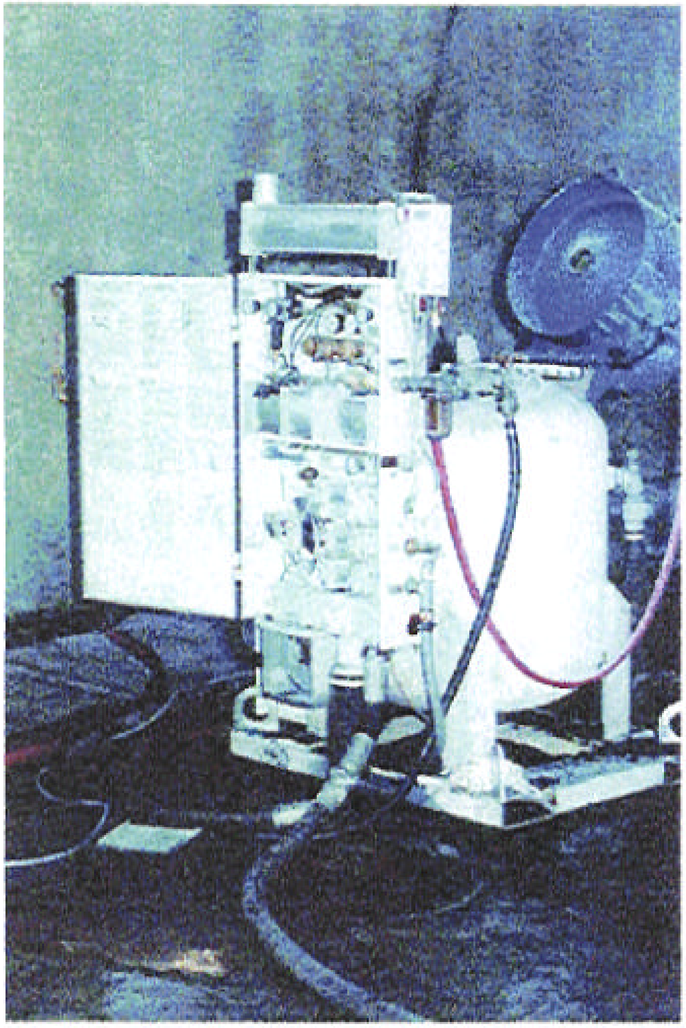
• Airline respirator (for under-hull tank work)

1994 air monitoring data for the LVWS operation was provided by Bangor Shipyard and was entered into the HADD. Additional air monitoring has not been performed by the shipyard on this work site since 1994, because the initial sample results established a very low exposure level for workers operating the Torbo™ unit. A Type CE blasting helmet was not used in the observed operation on the basis of these low exposure levels. Figures depicting the use of the LVWS blasting system are shown below.

Figure 24: Workers adjusting Low Volume Slurry Blasting (LVSB) unit.

Figure 25: Worker holding LVSB nozzle.

Figure 26:Open inspection panel on LVSB.



Containment with the Use of Recyclable Metallic Media (CRMM)

The NSRP project 3-94-2 provided data on a combined abrasive recycling and containment unit (using metallic abrasives). The demonstration took place in May, 1997 at Atlantic Marine, Jacksonville, FL. The demonstration provided data on the protection afforded a blaster by a Type CE blasting helmet when working within a containment. Evaluations were made of the following factors:

- Abrasive blasting productivity while using containment
- General utility of the containment
- Protection afforded the environment and other workers by the containment
- Protection afforded the blaster by Type CE helmet within containment

Abrasive Blasting Productivity

At least 15 blasting activities occurred on each of the two days of testing. The production rate while abrasive blasting ranged from less than 300 sq. ft./hr to over 800 sq. ft./hr, with a median of about 500 sq. ft./hr. These production rates were reduced by about 30% when taking into account other activities to maintain and move the containment. The coating being removed was a pre-construction primer of approximate thickness 0.75 mils. **The primer was a water-borne zinc containing coating.**

All work was conducted with a #7 (0.44 inch) nozzle. Pressure at the nozzle was measured at 100 PSI. The blasters; all wore the following the following items of PPE:

Type CE blasting helmet with face-shield external and safety glasses

Steel-toed boots

Reinforced gloves

Hearing Protection - ear muffs and ear plugs

Worker Safety and Environmental Monitoring

The concentration of total dust was measured at various areas in the shipyard (Table 2), as well as inside and outside the protective helmets of the blasters (Table 3). These data show that the abrasive blast helmet provided a widely fluctuating level of protection. This fluctuation was attributed to the improper function of the seals in the worst case reading. In neither case, however, did the Type CE blast helmet demonstrate the Protection Factor of 1000 that OSHA currently recognizes as attainable with this equipment. In addition, the dust levels outside the containment also did not vary from background level readings taken on days when blasting was not being performed. Comparison of dust levels inside and outside the containment demonstrate that the containment ventilation system did a superb job of providing entrainment and capture of dust generated during blasting operations (even though the vital dust collector was acknowledged to be operating at less than 50% of design capacity).

Table 2: Total Dust Concentration (mg/m³) at Various Areas Near Blast Work

Sample #	Total Dust (mg/m³)[a]	Blasting Day
JP051497-01[b]	0.065	No
JP051497-02[c]	<0.017	No
JP051597-01	0.041	No
JP051597-02	0.020	No
JP052097-01	0.018	Yes
JP052097-02	0.087	Yes
JP052197-01	0.100	Yes
JP052197-02	0.207	Yes

a - PEL (8 hr TWA) = 15 mg/m³ for total particulate, measured in accordance with NIOSH Method 0500.

b - 01 = Background measurement

c - 02 = Work area measurement

Table 3: Total Dust Concentration (mg/m³) Inside and Outside Blasting Helmets

Worker	Dust Inside Helmet (mg/m³)[a]	Dust Outside Helmet (mg/m³)	Protection Factor
1	0.114	28.8	253
2	0.340	5.26	15[b]

a - PEL (8 hr TWA) = 15 mg/m³ for total particulate, measured in accordance with NIOSH Method 0500.

b - Readings taken on 5/21/97 coincide with poorer functioning of seals.

The area monitored is shown in Figure 27.

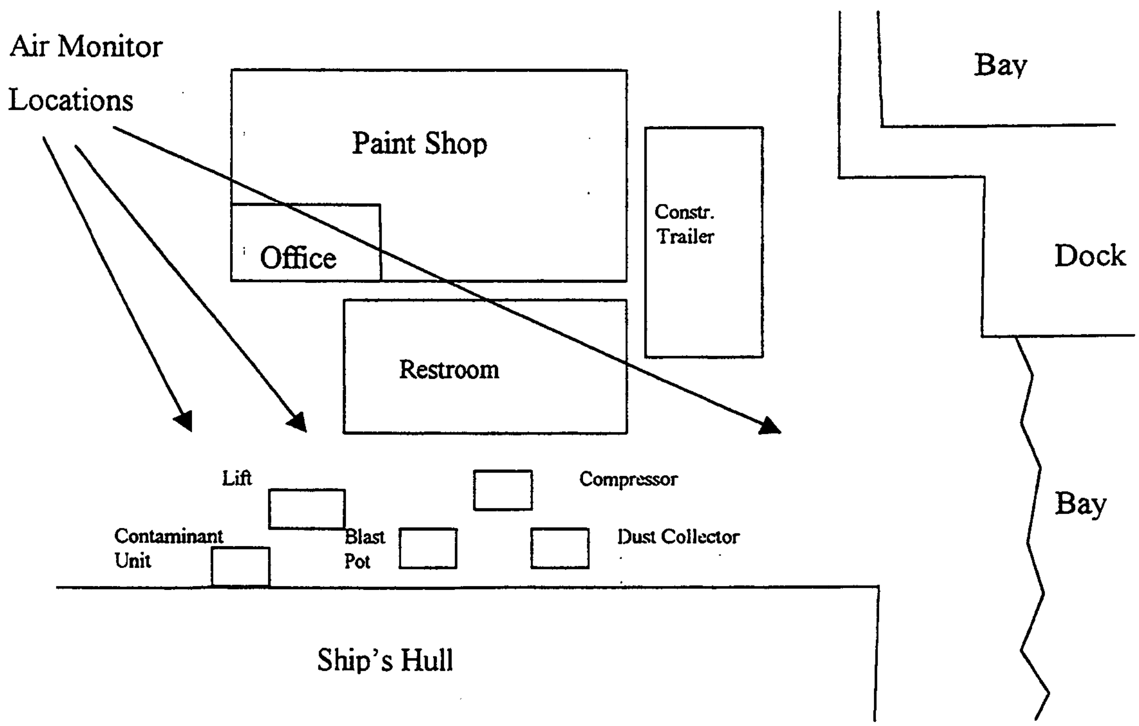
The containment efficiency can be estimated by comparing the dust levels inside the containment with those in the work area outside the containment. The computed efficiencies are above 96%.

The result of such a computation is shown below in Table 4.

Table 4: Estimating Containment Efficiency by Area Monitoring

Area Reading (A) mg/m³	**Reading Inside Containment (C) mg/m³**	**Efficiency 100 (1 - A/C)**
0.087	28.2	99.7
0.207	5.28	96.1

Figure 27: Placement of Area Monitors During Containment Evaluation



Data Analysis From "Hazardous Airborne Dusts Database" -HADD

The air sample data were collected from the participating shipyards and entered into the HADD. A total of 2,478 air sample entries for 39 contaminant types were entered. This data represents approximately 5 years of historical air sampling conducted in shipyards during the evaluation of target dust control methods used in surface preparation. The Methods used to collect the air samples were in accordance with OSHA and NIOSH methods using battery operated personal sampling pumps. An alternate approach considered during this project was to collect all new air sampling data. The compilation of extensive historical data was selected as the best approach for the bulk of the air sample collection in this project for the following reasons:

Volume of Air Sampline Data

It permitted the collection of a greater volume of air sampling data. New air samples collection, within the practical time and budget constraints of the project would have - at best - provided less than 10% of this data.

Scheduling

Scheduling of six different dust control methods for observation, at three participating shipyards cannot be done "on demand" to accommodate a research project. It is therefore very valuable to have access to the timely data that was collected "on the spot" when the surface preparation work occurred in the normal production schedule, rather than a set up demonstration.

Process Evaluation

Review of this data, and corresponding field notes, compiled by shipyard Industrial Hygienists, permitted our research team to examine the evaluation process followed by shipyards in comparing the effectiveness of dust control methods. This part of our field study emphasizes the need for an improved data collection process - linking production information with health and safety data. This was a significant contribution to this project - above and beyond the original scope - that proves to offer lasting value.

Consistent with other Industry-wide Evaluations

This approach is consistent with the approach followed by OSHA and trade associations when a new regulatory action is considered. Typically, data is requested and gathered from the affected industry to determine what level of control is reasonable and achievable. In addition, proactive data supplied by an affected industry may be able to demonstrate that adequate control methods are in place and no further regulatory action is necessary.

After entry into the database, the Data entry was subjected to a quality control audit and then processed through a series of custom queries and graphing for study and evaluation.

Listed below in Table 5 are the 39 contaminant types and the number of times each contaminant appears in the database.

Table 5: Contaminants Recorded in the HADD and their PELs (in mg/m3)

Aluminum - 21 (15)	Indium - 14 (0.1)	Respirable dust - 21 (15)
Antimony - 55 (0.5)	Iron - 73 (1)	Selenium - 6 (0.2)
Arsenic - 119 (0.1)	Iron oxide - 25 (1)	Strontium - 29 (15)
Asbestos - 1 (0.001)	Iron phosphate - 3 (1)	Tellurium - 13 (0.1)
Beryllium - 14 (0.002)	Lead - 627 (0.05)	Thallium - 7 (0.1)
Cadmium – 375 (0.005)	Magnesium - 51 (15)	Tin - 18 (0.1)
Chrome - 87 (0.5)	Manganese - 61 (5)	Titanium - 14 (15)
Chromic Acid – 3 (0.5)	Molybdenum - 57 (15)	Total dust - 35 (15)
Chromium - 257 (0.5)	Nickel - 86 (1)	Vanadium - 55 (0.5)
Cobalt - 54 (0.1)	Nuisance dust - 12 (15)	Welding fume - 2 (xx)
Copper - 214 (1)	Phosphoric acid - 3	Zirconium - 7 (5)
Fluoride - 1 (xx)	Phosphorous pentox - 1 (xx)	Zinc - 65 (5)
Formaldehyde – 2 (xx)	Platinum - 7 (15)	Zinc oxide - 29 (5)

A printout of the complete HADD is presented in the appendices. Graphs illustrating the range of sample results for each contaminant are presented below, including a depiction of the median results for each engineering control method entered into the HADD.

Figure 28 shows the total number of samples recorded for each individual contaminant when removed using one or another of the engineering controls described earlier, including:

- CRMM - Containment with Use of Recycled Metallic Media
- HPWJ - High Pressure Water Jetting
- LVWS - Low Volume Water Slurry Blasting
- SATR - Small Area Touchup and Repair with Power and Hand Tools
- VAB - Vacuum Abrasive Blasting
- OAAB - Open Air Abrasive Blasting
- Other

No results have been isolated for evaluation of Type CE blasting helmets (CFABH). These results have not been presented separately because CFABH are not a type of engineering control. Further, with the exception of the new data presented in Table 3, above, the data compiled on CFABH was not correlated with In-Out concentrations of dust for an evaluation of the level of protection provided. However, since most of the data entries for CFABH data also correspond to readings for one of the above paint removal methods, no process evaluation is lost by this exclusion.

Figure 29 shows the number of data points collected for each of the engineering control methods evaluated in the study. Together data points for lead and cadmium readings account for 889 of the total data points recorded for the engineering controls.

Figure 30 shows the average concentration of airborne lead for all engineering control methods. The highest level, as expected, is generated from dry abrasive blasting methods such as OAAB or CRMM. The wet methods, high pressure water jetting and water slurry, generated airborne lead levels below the PEL. These results must be used with caution in the absence of detailed data on the specific lead content of the paint being removed.

Figure 31 shows the average concentration of airborne cadmium for these same engineering controls.

Personal Breathing, Zone (PBZ) samples were collected in accordance with OSHA/NIOSH methods using battery operated pumps.

Sixty-eight readings for airborne dust are found in the HADD data. These sixty-eight readings are broken down as follows:

- Thirty-five readings are for total airborne dust;
- Twenty-one readings are for respirable dust;
- Twelve readings are for nuisance dust.

The HADD data for the dust readings is not traceable to contaminant concentrations of specific elements such as lead, cadmium, arsenic, etc., as hazardous airborne dusts. This is because dust data is often obtained on different days from chemical measurements and analysis is by a different laboratory method (gravimetfic).

Figure 29: Samples Collected for Each Contaminant

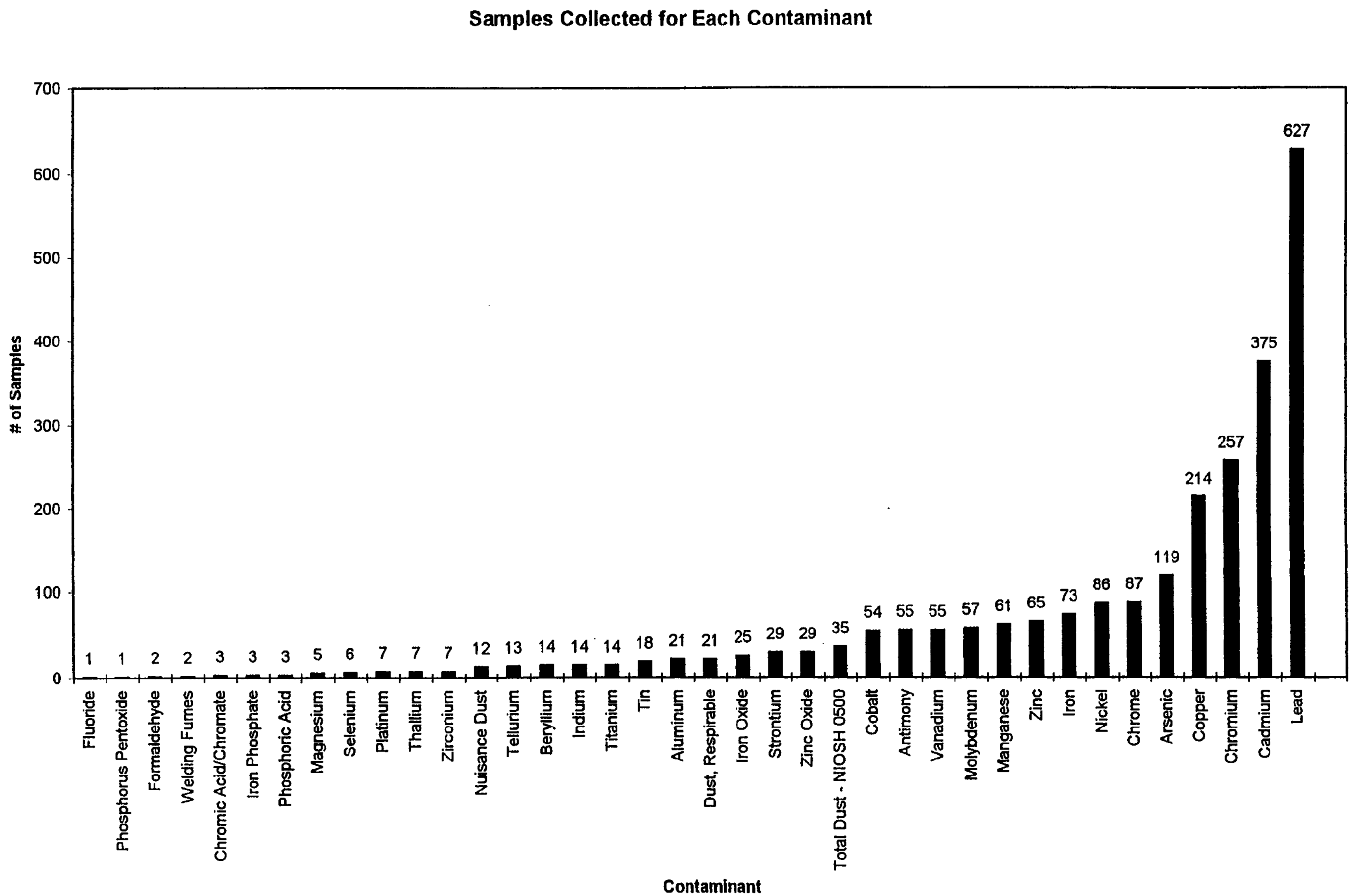


Figure 29: Samples Collected By Each Method

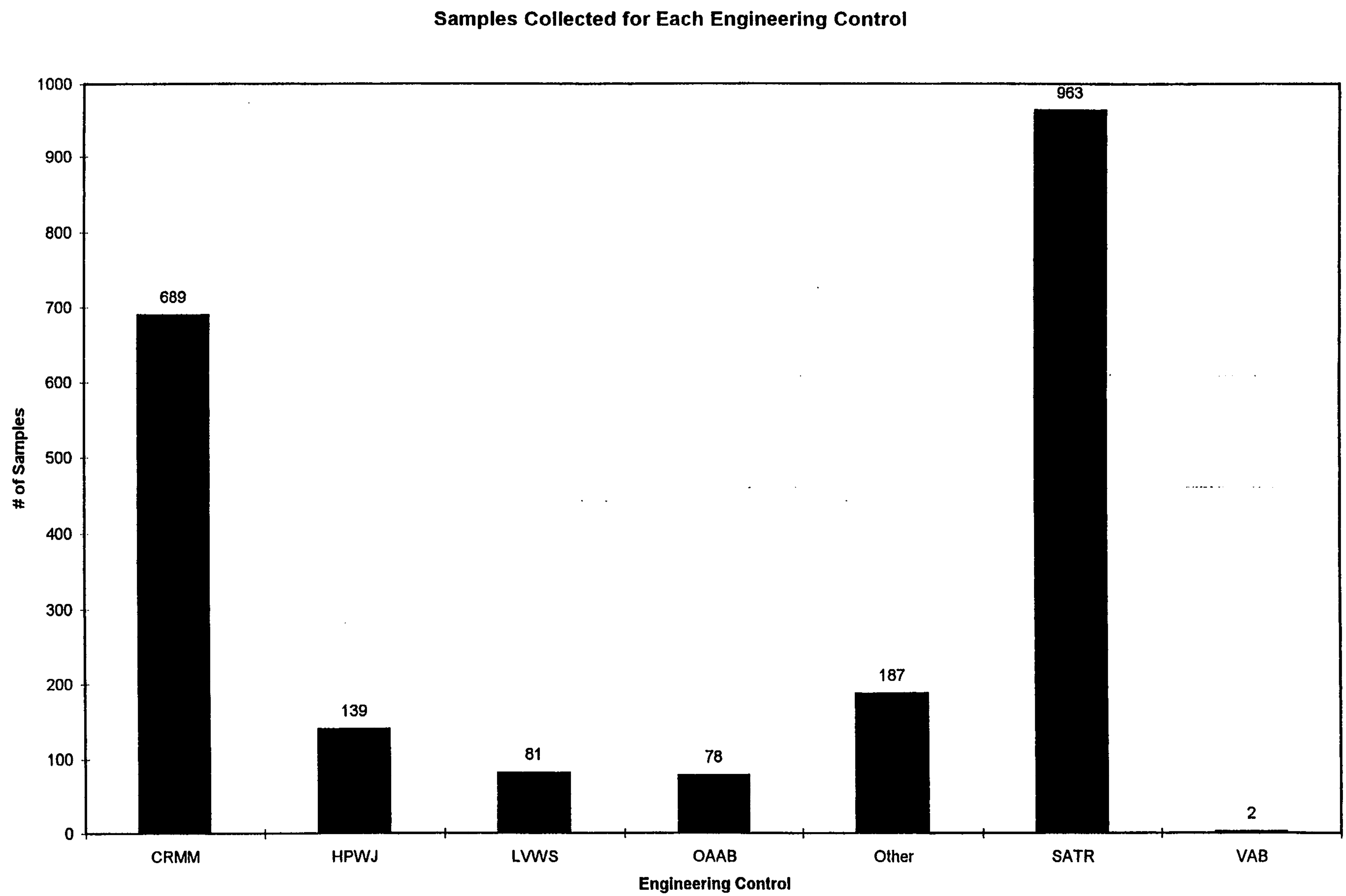
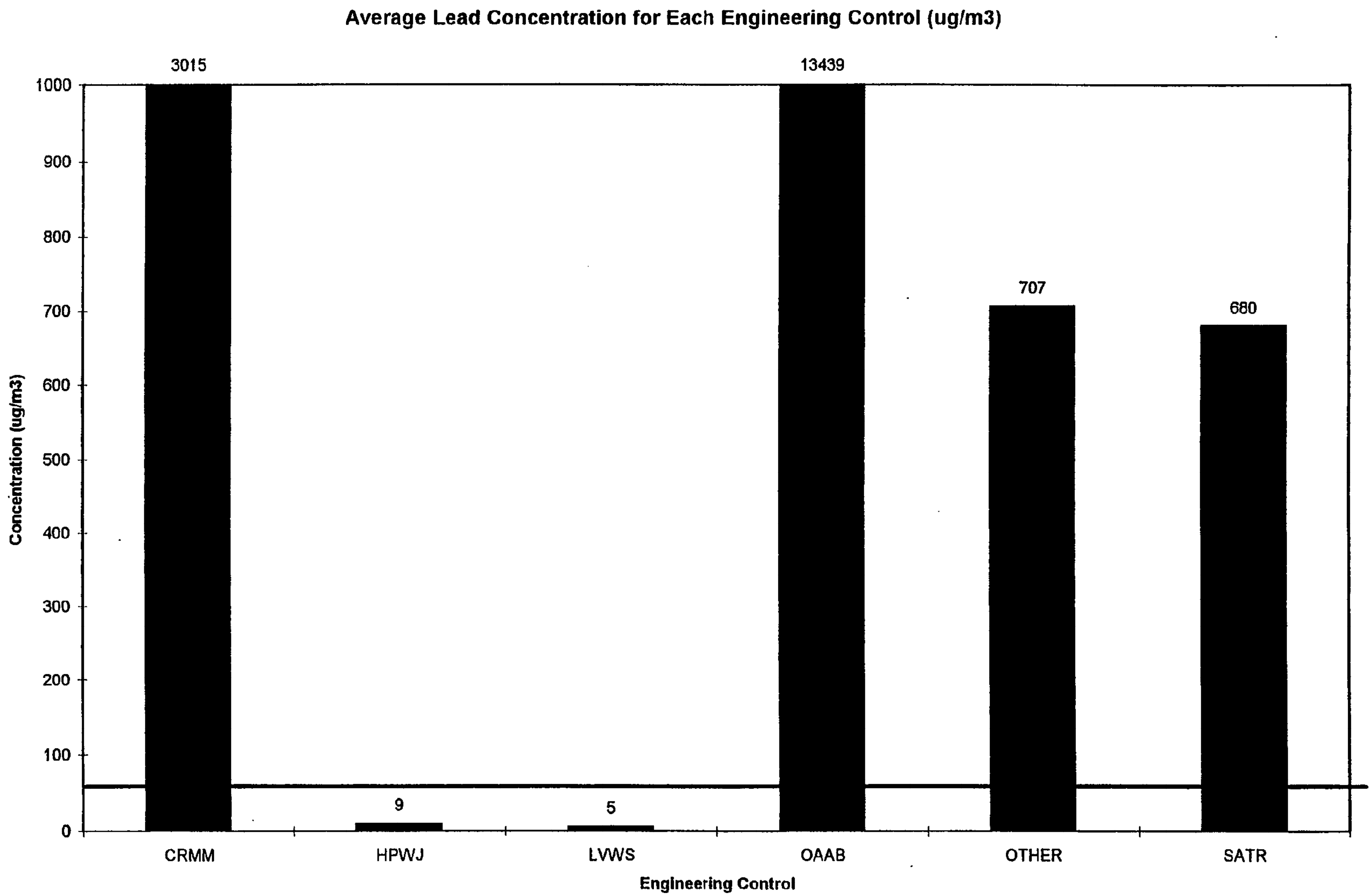
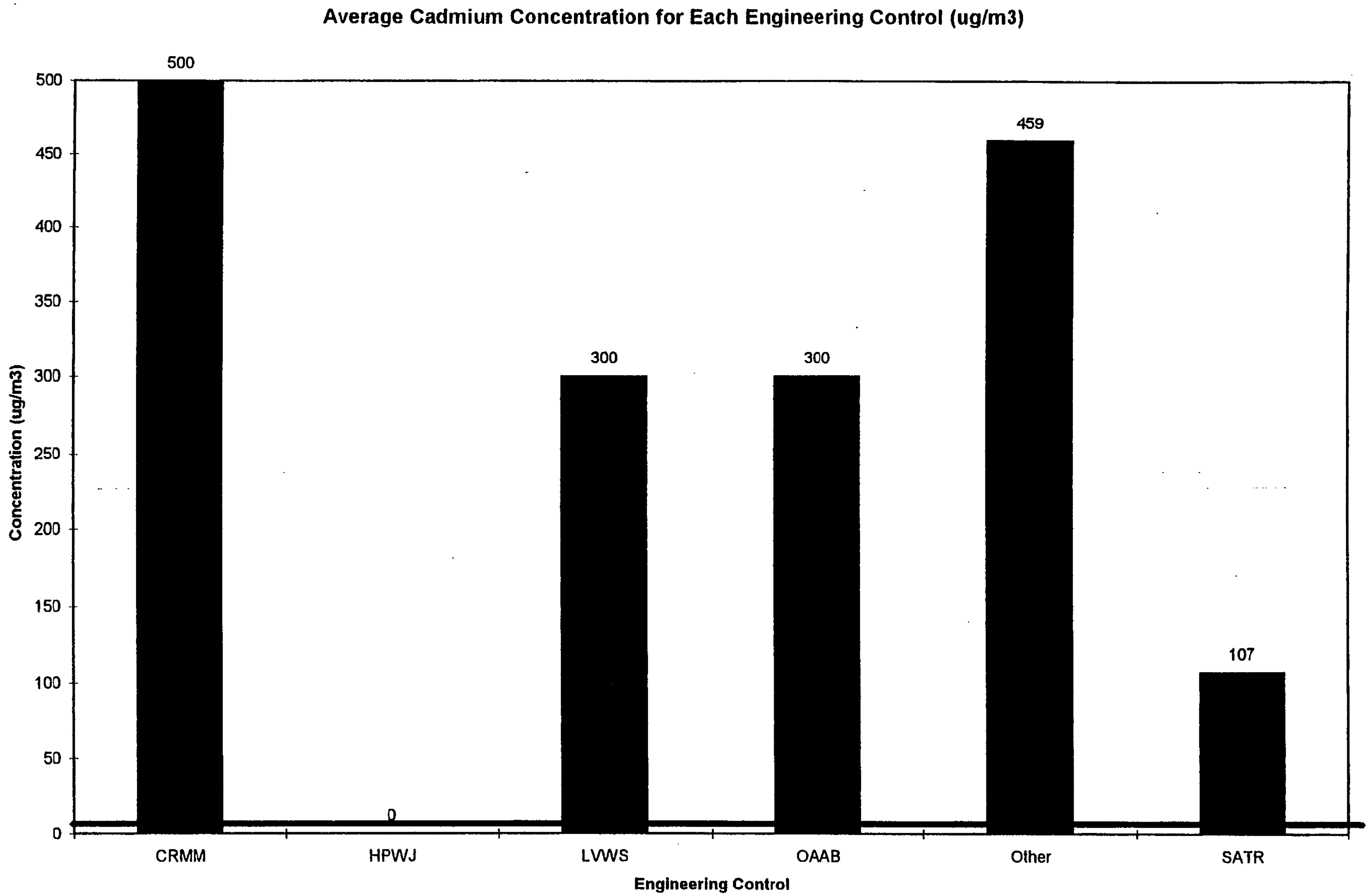


Figure 30: Average Concentration By Method



PEL = 50 ug/m3
CRMM Actual = 3,015
OAAB Actual = 13,439

Figure 31: Average Cadmium Concentrations By Method



PEL = 5(ug/m3)

Analysis of Engineering Controls from HADD Data

The HADD data allows evaluation of the likelihood of exceeding the PEL with each dust control method in place. The table below illustrates that the likelihood of exceeding the PEL during surface preparation is quite high, regardless of the contaminant present. More important, for hazardous dusts such as lead or cadmium, which may require the implementation of a medical monitoring program, the possibility of exceeding the PEL at other sites, under different conditions, cannot be excluded for each method that was evaluated.

Table 6: Instances of Readings Above PEL

		Contaminant		
Method:	Data	All Contaminants	Cadmium	Lead
CRMM	Times PEL exceeded	165	92	134
	Total Readings	689	207	338
HPWJ	Times PEL exceeded	0	0	0
	Total readings	139	25	25
LVWS	Times PEL exceeded	1	0	1
	Total readings	81	22	38
OAAB	Times PEL exceeded	21	7	12
	Total readings	78	21	36
Other	Times PEL exceeded	53	28	43
	Total readings	187	72	116
SATR	Times PEL exceeded	129	33	60
	Total readings	963	211	336
VAB	Times PEL exceeded	0	0	0
	Total readings	2	0	0

Table 7: Risk of Exceeding PEL with Engineering Controls

Method	**Risk of Exceeding PEL**		
	Any Contaminant	**Pb**	**Cd**
CRMM	24%	44%	40%
HPWJ	0%	n/a	0%
LVWS	1%	0%	3%
OAAB	27%	33%	33%
Other	28%	39%	37%
SATR	13%	16%	18%
VAB	0%	n/a	n/a

The values in Table 7 above compare dust levels of various airborne contaminants with their respective PELs. The fact that VAB (vacuum abrasive blasting) shows no instances of an exceeded PEL, or that LVWS blasting shows only one instance (for cadmium), does not demonstrate that these are universal engineering controls. Since only two data points out of more than 2000 go into the result for VAB, this is insufficient data on which to base a firm conclusion. Data from highway bridge lead paint removal suggests that VAB is successful in controlling hazardous airborne dusts if it is used correctly. VAB effectiveness under optimum conditions can be diminished by poor seal retention on the metal. With poor seal retention VAB is no better than OAAB in controlling hazardous airborne dust levels. Even when performed correctly, VAB is rarely selected for cleaning large surface areas as productivity has not been demonstrated to be comparable to the traditional dry abrasive methods.

The total number of data points for LVWS is higher (81). LVWS method has strong potential for wider use as an effective engineering control. Shipyards considering the use of LVWS to control hazardous airborne dusts should confirm the method's capability with independent monitoring. While HPWJ shows a low likelihood of resulting in exposures above the PEL, this is based on only 25 readings. By comparison, the traditional methods of abrasive blasting have been examined several hundred times. More air sampling data are needed on vacuum assisted blasting and LVWS or HPWJ paint removal methods would be valuable in further evaluation to determine how well they limit exposure to below a given PEL.

The more conservative conclusion from these data are that there is nearly a 10 to 30% chance that most dry methods of paint removal will result in an exposure above the PEL. Whether such an exposure will occur depends on the type of coating being removed. This means that in the absence of a negative initial determination found through current site specific air monitoring data, the affected shipyard must be ready with medical monitoring and a compliance program when it is known that a coating containing lead, cadmium or other regulated pigments is being removed.

Economic Analysis of Dust Control Implementation

To determine the best dust control application requires knowledge of three characteristics for the control method:

- The ability of the method to reduce worker exposures and dust emissions, (this was described in the preceding section on the analysis of data from the engineering controls evaluations).

- The cost impact of using the engineering control in place of established industry practices.

- The suitability of the control method to the particular task of surface preparation.

This section of the report presents a simple approach for estimating the cost to implement one of the engineering controls evaluated in the study, in the form a cost model. The model presented can serve as the basis for determining the costs to implement any of the other engineering control methods. Our example, presented in this model compares the cost to implement CRNW with that to implement OAAB. For any engineering control the costs of implementation are divided into equipment, materials, labor and components.

General Approach for Cost Modeling

The approach taken in preparing our example cost model for the engineering control methods was as follows. First, the cost for operating the engineering control is assessed. Second, we estimate the rate of cleaning with each method. The rates are given as square feet of cleaning per hour for typical tasks. Third an estimate is made of the number of hours of production per year, for each engineering control. From this data one can compute equipment costs in dollars per square foot of cleaning. The specific costs and productivity assessments used in our example model derive from the following studies, projects and reports:

- NSRP Projects 3-94-2 "Combined Abrasive Recycling and Containment." This provides data on actual productivity of a CRMM engineering control for hull coating removal, data on costs to procure the containment structure and support equipment, and costs for operating the containment.'
- NSRP Project 3-95-7 "Users Guide to Selection of Abrasives." This study provides industry data on the productivity for typical tasks. Data for a wide variety of mineral and metallic abrasives is presented.
- NSRP Report 0387 Feasibility Study Tank Blasting Using Recoverable Steel Grit." This report provides the core of our cost model for converting costs of operation, and use of abrasive

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[1] The example in the cost model is limited to data for use of recyclable metallic abrasive in containment, as defined by the engineering control method CRMM.

blasting methods, into costs for each square foot of cleaned surface.

An overall recommendation for the engineering control implementation is given last, based on three factors. This recommendation uses the figures from the cost model as one factor. A qualitative assessment of the suitability of each method to individual shipyard surface preparation tasks is used. The last factor is the previously determined protective capabilities for each method. There are a very wide number of variables involved in shipyard surface preparation and coating. It is impossible to report overall costs for all the combinations of tasks and equipment within each engineering control. This economic analysis is intended to be representative. It should serve as a model for similar efforts by readers of the report, which may, in time, be used to evaluate new tasks or equipment. The general cost modeling approach is illustrated in this section for two of the engineering controls. The engineering controls compared in this section are:

- OAAB Open Air Abrasive Blasting, and
- CRMM Containment with Recycling of Metallic Media

The costs for the use of each of these engineering controls are assessed for two levels of cleaning, termed Level 1 and Level 2. Level 1 cleaning is to SSPC-SP 10 "Near White Metal Blast Cleaning" while Level 2 cleaning is to SSPC-SP 7 "Brush-Off Blast Cleaning." For OAAB the media assumed was a mineral grit having a bulk density of approximately 100 lbs. per cubic foot, while for CRMM the assumed abrasive is a metallic grit, with a density of 300 lbs/ft^3 . For each case the assumed operating conditions are the use of a #8 (1/2 inch) nozzle, with pressure at the nozzles of 100 PSI. Other engineering controls were not subjected to similar cost modeling exercises though estimates of their costs were made. The result of cost modeling for the two example controls is given later in Table 16.

Cost Components

The cost elements used in these models include:

- Cost of capital equipment of components (amortized over five years).
- Cost of operation (maintenance, operation, shutdown, repair, utilities, etc.).
- Cost of consumable items (abrasive, hoses, nozzles).
- Costs for worker protection (PPEs and training).
- Costs for protecting public, environment and adjacent workers, costs for waste disposal.
- Labor costs for surface preparation.

Converting Quantifiable Costs to Dollars For Each Square Foot of Cleaning

The type of data presented in this section includes costs presented as:

- Dollars per Year of Operation Cost Data Type 1
- Dollars Per Hour of Operation Cost Data Type 2, and
- Dollars per Square Foot of Cleaning - Cost Data Type 3

In this section these numbers are all reduced down to a common base of dollars per square foot of cleaning. To accomplish this the following calculations are made.

- Cost Data Type 1 is divided by the estimated number of square feet of cleaning achievable in a calendar year, this is explained in greater detail below.

- Cost Data Type 2 is divided by the estimated number of square feet of cleaning per hour shown in the table "Productivity Rates for Engineering Controls."

- Cost Data Type 3 is used directly.

The assumptions made in deriving costs per square foot of cleaning for costs computed in terms of dollars per year are as follows:

- There are 1500 work hours assumed per year for each engineering control method.

- The total number of square feet of cleaning each method is capable of producing is given by 1500 hrs. X number of square feet of cleaning to either Level 1 or Level 2.

We also assume an average loaded labor rate (including overhead) of $40 per hour. For each method and level of cleaning the cost per square foot of direct labor is computed by dividing the labor rate by the total area cleaned

Cost of Capital Equipment

In our model we assume that there are amortized capital costs for the equipment, whether it represents a new purchase or is likely to already be part of the shipyards inventory of equipment. For each type of control we list the equipment components required, assign estimated costs for procurement of those items of equipment, then amortize the costs over a five year time span.

Costs of Equipment for OAAB

The equipment costs for OAAB are tabulated below. Some data is taken from the NSRP Project Report 0387 and has been adjusted for inflation. All data has been validated by consultation with equipment suppliers. This data does not include costs for nozzles and hoses which are treated as consumable items. Costs for rigging and scaffolding for the OAAB method are not treated as equipment costs to the paint department. Costs for a high lift device to support the type of containment unit used in NSRP Project 3-94-2 are included for the CRMM method.

Table 8: Equipment Procurement Costs for OAAB & CRMM

Component	Approximate Procurement Cost	
	OAAB	CRMM with High Lift
Air Compressor (1300 CFM Portable)	$80,000	$80,000
Blast Pot (Pressure Type)	$16,000	$16,000
Air Dryers and After Coolers	$23,000	$23,000
Moisture and Oil Separators	$1,200	$1,200
Dust Collector (12,000 CFM)	$60,000	$60,000
Total Equipment Costs	$180,200	$180,200
Abrasive Recycling Unit for Containment		$26,000
Grit Recycling and Cleaning Unit		$9,000
Vacuum PD Air Pump		$3,000
High Lift (Condor)		$350,000
Containment Unit		$15,000
Total Cost	$180,200	$583,200

Costs of Equipment for CRMM

The equipment costs for a CRMM system are taken from the report on NSRP Project 3-94-2 Task C "Field Evaluation of a Prototype Combined Abrasive Recycling & Containment Unit," and also from the NSRP Project Report 0387.

Amortized Capital Costs for the Two Methods

Taking the equipment procurement costs for each of the methods defined above one can calculate the amortized cost of this capital investment over a five-year period. This results in an annualized cost for each equipment see the two equipment sets.

Table 9: Annualized Capital Costs

Engineering Control	Total Procurement Cost	Annual Cost of Capital (a)
OAAB	$180,200	$38,268
CRMM w/ High Lift	$583,200	$123,852
(a) - Assuming 3% inflation for each of the five years.		

Estimating Productivity of Each Engineering Control

To reflect the incremental effect of equipment costs on the costs to clean each square foot of surface one must know the overall productivity of each engineering control as a cleaning method. Considerable industry data on the productivity of the different methods has been accumulated by SSPC for this and other NSRP Projects.

Abrasive blasting productivity information is available from data sets created for NSRP Project 3-94-2, "Combined Containment with Recycled Abrasive Blasting," and NSRP Project 3-95-7, "Users Guide to Selection of Abrasives." Data for other methods comes from prior mentioned sources for SATR and HPWJ methods.

The assumed surface being cleaned is a multi-coat system (such as a 3-coat epoxy) of 10-12 mils thickness. Listed below are the estimated peak productivity rates for each of the methods under the operating conditions described earlier, for surface preparation to the two levels of cleanliness.

These costs can converted to costs per square foot of cleaning as follows.

Cost per Square Foot = Cost Per Year / (Hours of Use per Year x Square Feet of Cleaning Per Hour).

It is estimated that the unit will be used for 1500 hours each year. Typical production rates are given in the table below, along with the costs of equipment for each square foot of cleaning.

Table 10: Productivity Rates for Engineering Controls

Engineering Control	Cleaning Rate SSPC-SP 10 ft2/Hr	Equipment Cost Per ft2/Hr SSPC-SP 10	Cleaning Rate SSPC-SP 7 ft2/Hr	Equipment Cost Per ft2/Hr SSPC-SP 7
OAAB	290	$0.09	2000	$0.01
CRMM w/ High Lift	190	$0.43	1300	$0.06

Cost of Operation

The costs to operate each of the engineering control systems varies in rough proportion to the number of pieces of equipment used and the fuel or utilities required for their operation. Other contributory operating costs include times for maintenance, training, shut-down and repair. Operating costs depend on several factors such as; the utility requirements, power, fuel, and the relative amount of maintenance required.

The overall productivity for our two methods reflects typical achievable cleaning rates during a full day of normal operation. This overall productivity thus accounts for all maintenance activities, set-up and shut-down times, normal stoppages for replenishing media or tool parts, and other required activities.

The elements for the costs of operation and their estimated amounts are shown below, expressed in terms of dollars for each hour of equipment operation. The figures given combine operation, maintenance and training costs. They are derived for the most part from the figures given in NSRP Report 0387, adjusted for inflation, or from estimates made during the field trials of the CRMM prototype under NSRP Project 3-94-2.

Table 11: Operation Costs for Each Engineering Control

Cost of Operation $/hr		
Cost Element	OAAB	CRMM w/High Lift
Air Compressor (1300 CFM Portable)	$30.00	$30.00
Blast Pot (Pressure Type)	$0.25	$0.25
Air Dryers and After Coolers	$1.50	$1.50
Moisture and Oil Separators	$0.25	$0.25
Dust Collector (12,000 CFM)	$6.00	$6.00
Grit Recycling and Cleaning Unit		$0.25
Vacuum PD Air Pump		$1.10
High Lift (Condor)		$6.00
Total Cost	$39.35	$45.35

These can be converted to $/square foot of cleaning by dividing by the productivity estimates shown above. The results of such a calculation are shown in Table 12, below.

Table 12: Cost of Operation for Each Sqaure Foot of Cleaning

Costs of Operation $/ft^2		
Cost Element	OAAB	CRMM w/High Lift
Total Cost	$39.35	$45.35
Cleaning Rate SSPC-SP 10 ft^2/hr	290	190
Cleaning Rate SSPC-SP 7 ft^2/hr	2000	1300
Cost of Operation $/ft^2 SSPC-SP 10	$0.14	$0.24
Cost of Operation $/ft^2 SSPC-SP 7	$0.020	$0.035

Costs Of Consumable Items

These are presented below for each engineering control in terms of dollars per hour. They are derived from the same sources used earlier. The major consumable for surface preparation is the abrasive as shown in Table 13, below. For OAAB (and the un-modeled LVWS method) the abrasive type is a non-metallic abrasive. The usage rate is estimated at 10 pounds per square foot of cleaning to achieve an SSPC-SP 10 "Near White Metal Blast Cleaning," and 1.5 lbs per square foot to achieve an SSPC-SP 7 "Brush-Off Blast Cleaning" finish condition. Both CRMM and the un-modeled VAB methods use metallic abrasive. This has approximately three times the bulk density of many mineral abrasives, but can be reused quite efficiently. The higher density improves the rate of cleaning for each cubic foot of abrasive. Assuming a (relatively pessimistic) reuse rate of 90% on each recycle typical cumulative use rates for metallic abrasives are 1.5 pounds per square foot for SSPC-SP 10 and 0.25 pounds per square foot for SSPC-SP 7 cleaning. Thus typical use rates of mineral abrasive are 1.5 tons for each hour of cleaning, and roughly 0.15 tons per hour for metallic abrasive use. Based on a cost for metallic abrasive of $400 per ton, and mineral abrasive of $100 per ton the relative costs per square foot for each level of cleaning are shown below. Costs for other consumable items (such as hoses, nozzles and other items) are minuscule, amounting to between $0.01 to $0.02 per square foot.

Table 13: Abrasive Cost for CRMM Control Compared to OAAB[a]

Costs for Media $/ft^2		
Engineering Control	SSPC-SP 10	SSPC-SP 7
OAAB	$0.50	$0.08
CRMM w/ High Lift	$0.30	$0.05

a - If a less conservative recyclable factor is assumed then CRMM material costs are reduced.

Cost for Worker Protection

The worker protection costs are dictated by the type of Personal Protective Equipment (PPE) worn when using each method. These costs are summarized in terms of dollars per year for each method in the table below. The identity of typical PPEs is given by data obtained during field visits at US Shipyards conducted as part of this project. Costs are estimated for each set from manufacturer data.

Table 14: Worker Protection Costs for Each Engineering Control Method

Worker Protection		$ Per Year					
	OAAB	LVWS	HPWJ Basic	HPWJ Closed Loop	CRMM	SATR	VAB
Type CE Helmet	$ 500	$ 500			$ 500		$ 500
Visor	$ 50	$ 50			$ 50		$ 50
Safety Glasses	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20
Hearing Protection	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20	$ 20
Rain Gear			$ 150	$ 150			
Half Face Respirator						$ 150	
Dust Cartridges						$ 150	
Total Annual PPE Cost	$ 590	$ 590	$ 190	$ 190	$ 590	$ 340	$ 590

Worker protection costs include the costs for PPE and any added labor costs for training, plus added overhead costs for trainers and training materials. Shipyards have recurring costs for these items. It is assumed that all workers require basic PPE including ear, hearing, foot, head, and eye protection. Such costs for equipment and training are not separately considered here. Additional training costs are incurred where workers are potentially exposed to hazardous materials such as lead or cadmium. Under conditions of expected exposure to such hazardous materials there are additional specific training and monitoring requirements. The nominal estimated cost for worker protection and training is estimated at $1.00 per square foot for SSPC-SP 10 cleaning, $0.20 for SSPC-SP 7 cleaning. This is based on data from bridge and other lead paint removal projects. (This represents the low end of the range of costs for enhanced workplace monitoring, worker medical surveillance, and training to deal with hazardous materials, the actual reported range was between $1.00 to $4.00).

A further added cost for worker protection is incurred when specific equipment is used. For example, when abrasive blasting hazardous metals in containment an abrasive helmet with an enhanced protection factor of 1000 is preferred. The additional cost of such equipment is modest when measured in dollars for each square foot of cleaning. This amounts to less than $0.02 and is not considered here.

Costs for Waste Disposal

In this section, only the quantifiable costs associated with waste disposal are given. Other environmental protection factors, such as protection of adjacent workers are already accounted for in the costs to operate an individual engineering control which limits dust emissions (such as CRMM) or are discussed qualitatively in the section on "Other Costs."' The given environmental protection costs for waste disposal depends on two factors. First, is the waste hazardous or non-hazardous. Second, there is a dependency on the degree of cleaning needed. The quantity of waste material per hour of operation remains nearly constant for both levels of cleaning. Other assumptions factoring into the calculations for waste disposal that apply to OAAB, CRMM include:

- Median hazardous waste disposal cost is estimated at $240/ton and does not include transportation cost of $20/ton (up to 1000 miles).
- Costs of laboratory tests to profile the waste are not included.
- For any method, disposal costs will depend on the production rate and the density of the abrasive. Assume a mineral abrasive with a density of approximately 100 lbs. per cu. ft.
- In general, disposal costs for hazardous waste are 4 to 5 times more than for non-hazardous waste.

Assumptions that apply to other method include the following.

- Costs for HPWJ assumes no abrasive injection.
- Using an estimate of 0.1 lb./SF of paint and rust debris generated if no abrasive is included (i.e. power tools & HPWJ)
- Costs for water collection and filtration are not included (these costs would be accounted for in the equipment operation costs for the HPWJ - Closed Loop method).

Based on these assumptions the table below describes waste disposal costs in dollars per hour for four scenarios:

- Disposal of Hazardous Waste - Production Level 1 SSPC-SP 10
- Disposal of Non-hazardous - Production Level 1 SSPC-SP 10
- Disposal of Hazardous Waste - Production Level 2 SSPC-SP 7
- Disposal of Non-hazardous Waste - Production Level 2 SSPC-SP 7.

- Disposal of Non-hazardous Waste - Production Level 2 SSPC-SP 7

The data presented in Table 15 indicate that this cost burden is only severe if the waste being disposed of is characterized as a hazardous waste.

Table 15: Waste Disposal Costs for Each Engineering Control Method (Dollars Per Square Foot of Operation).

	OAAB $/ft^2	CRMM w/High Lift $/ft^2
Disposal Hazardous Production SSPC-SP 10	$1.20	$0.18
Disposal Hazardous SSPC-SP 7	$0.18	$0.030
Disposal Non-Hazardous SSPC-SP 10	$0.20	$0.03
Disposal Non-Hazardous SSPC-SP 7	$0.030	$0.005

Using the figures of abrasive use derived earlier we estimate the contribution to square foot cost by multiplying the amount of abrasive used per hour (in tons) by the cost of waste disposal. These abrasive use rates are 1.5 tons per hour for mineral and 0.15 tons per hour for metallic abrasive. The resultant cost of disposal per hour is then divided by the productivity rates previously given for each method and cleaning level in Table 10.

Comparing Overall Costs of Blasting Methods

The results of these calculations are shown below for the major cost elements in our model in Table 16, below.

The overall equation for cost per square foot of cleaned surface for each combination of desired level of cleaning (SSPC-SP 10 or SSPC-SP 7) with original material type (hazardous or non-hazardous) when achieved with either the OAAB or CRMM method is as follows:

Total cost per square foot (TCS) is = Annualized Capital Cost of Equipment (ACC) + Equipment Operating Cost (OC) + Cost of Consumables (CC) + Worker Protection Cost (WPC) + Waste Disposal Costs (WDC) + Cost of Labor (LC)

TCS = ACC+OC+CC+WPC+WDC+LC

Table 16: Total Cost for Engineering Control Use

	Costs $/ft^2$			
Cost Element	OAAB		CRMM w/High Lift	
	SSPC-SP 10	SSPC-SP 7	SSPC-SP 10	SSPC-SP 7
Annual Cost of Capital	$0.09	$0.01	$0.43	$0.06
Operating Cost	$0.14	$0.02	$0.24	$0.03
Costs of Consumables	$0.52	$0.08	$0.30	$0.04
Labor Costs	$0.10	$0.02	$0.16	$0.02
Waste Disposal Costs (Hazardous)	$1.20	$0.18	$0.18	$0.03
Waste Disposal Costs (Non-Hazardous)	$0.20	$0.03	$0.03	$0.01
Worker Protection Costs (Hazardous Onl	$1.00	$0.20	$1.00	$0.20
Total Costs (Non-Hazardous)	$1.04	$0.16	$1.16	$0.16
Total Costs (Hazardous)	$3.04	$0.51	$2.31	$0.39

This analysis indicates that CRMM is most cost effective as an engineering control only when there is a need to handle hazardous waste materials. A significant assumption made in our estimate is the assignment of a 90% reuse factor for the metallic abrasive. Enhancing the reuse level for the metallic abrasive would make CRMM more competitive in situations where non-hazardous paint removal was being considered. Also this model does not explicitly account for the reduction in dust with CRMM. This dust reduction can result in an improved workplace for adjacent workers, improving their productivity.

NOTE: Detailed cost modeling was undertaken for two of the methods. OAAB and CRMM. For other methods our ratings of costs given in Table 17 were estimated based on our review of current practices, related surveys, published literature and discussions with owners, contractors and suppliers.

Comparative Assessment of Engineering Controls

The overall comparative assessment of engineering controls is conducted through a ranking of the methods against critical performance or productivity factors. Following this ranking the suitability of the ranked methods to conduct individual tasks is assessed. A method to rank surface preparation methods was developed as part of the Industrial Lead Paint Removal Handbook, Second Volume, "Project Planning." The method assigns values on a 1 to 5 scale to such factors as:

- Degree of Worker Protection - Worker/Blaster
- Degree of Worker Protection - General Work Area
- Quantity of Waste Produced
- Productivity
- Cost for Capital Equipment
- Cost of Cleaning (per Square Foot), and
- Surface Cleaning Capability.

To provide an overall assessment of engineering controls a qualitative evaluation of each method is conducted against these parameters which are discussed below.

Evaluation Parameters

The evaluation scale is a rating from 1 to 5, with five being the worst rating.

Degree of Worker Protection - Worker/Blaster

Worker protection is a critical parameter. The parameter measured is the amount of total or hazardous airborne dust generated for the operator during use in the workers' breathing zone. We use the HADD data to provide a means for evaluating the methods against this parameter. This is worst for methods which capture dust emissions from abrasive blasting into a containment. Ratings are also very poor for methods (like OAAB) which provide no control over dust emissions and use a mineral abrasive. This rating point and that which follows also address the needs of shipyards concerned with controlling nuisance dusts and PM-10 emissions.

Degree of Protection to Other Workers and the Environment

This parameter also measures the degree of generation of total dust by each of the methods. The dust is measured in the general work area, not in the operators breathing zone. Air quality is impacted by total dust (nuisance dust) and respirable dust (PM-10 (particles smaller than 10 micrometers in diameter)). Although the HADD data is limited in background readings, the values for breathing zone levels provide adequate guidance for all except the CRMM method. Independent data from the 3-94-2 Project is available to permit an assessment of the CRMM method.

Degree of Waste Generation
This is a straightforward rating parameter. The volume of waste generation combines two types of data-, volume of waste generation and, ease of clean-up of the waste. Methods which do not use abrasives score well against this parameter. Methods which recycle or reuse cleaning media also score well.

Productivity
The faster the method will clean, the better the rating is against this parameter. Methods which are intrinsically low in productivity, or which tire the worker causing a fall-off in productivity level, score poorly against this parameter. Productivity will also vary dependent on the specific task
.

Capital Equipment Costs
Higher capital costs will result in a poorer score against this rating. Some yards may not be willing to make a large capital investment because of budget restraints or uncertainty about extent of use.

Cost Per Square Foot of Cleaning
This combines all the cost factors as computed earlier for each method. The lower the cost per square foot of cleaned surface, the better the rating against this parameter.

Surface Cleaning Capabilities
This parameter is used to evaluate the range and number of degrees of cleaning each method can achieve. Methods like OAAB which can easily produce a very wide range of cleaned surface conditions score well in this category. Other criteria for surface cleaning capabilities include: surface quality or surface roughness (profile), absence of rust, paint, and other visible contaminants, and absence of soluble salts.

Each of the engineering control methods is rated against these parameters in the following section.

Review of Capabilities of Each Method

OAAB - Open Air Abrasive Blasting Ratings
Open Air Abrasive Blasting, OAAB scores well in the areas of productivity and surface cleaning capabilities, for both areas it receives a rating of one. OAAB scores most poorly in providing worker protection to both the blaster and other workers in the general area. It also scores poorly in providing protection to the environment. In addition OAAB also obtains a poor score for potential high volume waste generation. All these factors are given the lowest possible (5) rating. The capital equipment costs for OAAB are reasonably low, meriting a rating of two. The cost of cleaning per square foot is the second lowest of the methods, (for instances where the waste is non-hazardous) hence this also receives a two rating.

CRMM - Containment with Recycled Metallic Media Ratings
The CRMM method gets the highest scores for protection of workers in the general environment and work area and for surface cleaning capabilities. The worst scores CRMM obtains (5) are for protection of the blaster and for capital equipment costs. Even with ventilation adequate for good visibility there is a risk of high exposure to the worker in containment. As localized dust collection systems are used more effectively, this rating should improve. The poor rating for capital equipment costs must be balanced against the impact this has on the overall cost per square foot of cleaning. This cost is nearly as low as that for OAAB, hence it receives a rating of three. One of the main reasons for the good costs per square foot of cleaning is the low level of waste generated. The CRMM method also receives a rating of two for this parameter (HPWJ being judged better at reducing overall waste). Productivity is not as good as OAAB and receives a rating of two.

SATR - Small Area Touch-Up and Repair Ratings
For degree of protection of the worker, the general environment, and for waste generation SATR receives a rating of two. The lowest rating (5) SATR receives is for productivity. The highest rating (1) is for costs of capital equipment, which costs are the lowest of any method. Because of the low productivity the cost of cleaning each square foot is also high and receives a rating of four. The surface cleaning capabilities of SATR are somewhat limited. There are really only two levels of cleaning afforded by the method, either cleaning to bare metal (SSPC-SP 11) or simple power tool cleaning (SSPC-SP 3). For this reason SATR receives a rating of three for this parameter. Also the method is ineffective in removing soluble salts.

LVWS - Low Volume Water Slurry Blasting Ratings
This method is given the highest rating (1) for protection of the worker, the general environment and work area, because the water suppresses the dust. Like other abrasive blasting methods LVWS receives the highest rating for surface cleaning capabilities. The method is judged slightly better than OAAB in controlling waste generation where it receives a rating of four. Being slightly less productive than OAAB the LVWS method receives a rating of two for productivity, and consequently a rating of two for cost per

square foot of cleaning. The cost of cleaning is governed by productivity, costs for capital equipment are only slightly higher than those for OAAB. The higher capital costs result in a rating of three for this parameter. The likelihood for flash rusting with LVWS is lower than that for HPWJ.

HPWJ - High Pressure Water Jetting Ratings

The HPWJ method is judged to be the best way to consistently protect the worker, the general work area and the environment from dust emissions. It receives a rating of one in each of these categories. HPWJ is also judged to produce the lowest volume of solid waste material. HPWJ can provide difficulties in the handling and treatment of mixed paint debris and water. In the case a closed loop HPWJ system (such as that tested by the US Navy) a rating of 1 is also merited. All water is recycled and only the solid waste product is recovered for disposal. A closed loop BPWJ system does have the highest rating for capital costs. More typical HPWJ equipment uses between one and three gallons of water per minute. This must be separately collected and treated prior to disposal in accordance with the environmental regulations. Our rating for capital equipment for HPWJ without continuous recovery of waste water is two, it is judged to be more expensive than OAAB. The rating for waste generation for such a system is also two, reflecting the need for collection and handling of waste water. The overall productivity of the method is judged as comparable to that of CRMM or LVWS blasting when used at very high pressures above 25,000 PSIg. Because of the low solid waste disposal costs, the lower assumed capital equipment costs, and reasonable productivity, the overall costs per square foot are judged to be the lowest of any method. The cost per square foot for IHPWJ thus is given a rating of one. HPWJ is rated at three for surface cleaning capabilities, its worst rating. This poor rating is given because the method cannot create a profile, nor can it remove existing millscale. Moreover, it is sometimes the case that a HPWJ cleaned surface will require follow-up cleaning to remove flash rusting.

VAB - Vacuum Abrasive Blasting Ratings

The VAB method when used correctly will result in excellent control of dust emissions to the worker, the general workplace and the general environment. Like other abrasive blasting methods VAB provides a large number of ranges of cleaning. In all these three areas VAB receives the highest possible rating of one. Assuming that the VAB method is used with metallic abrasive the level of waste produced is going to be comparable to that from CRMM, likewise it receives a rating of two in this category. VAB receives lower ratings in the areas of productivity and cost per square foot. Productivity is hampered by two factors: first the method is usually conducted with lower nozzle pressures; second, the method is tiring to the worker. Both factors contribute to a very low overall productivity rating of five. Largely because of the poor productivity rating for VAB (roughly comparable to that for SATR) the method receives a rating of four. Capital equipment costs are higher than those for OAAB, and a rating of three is merited.

Summary of Ratings of Each Method

The ratings for each method for each of the parameters are shown below in Table 17.

Table 17: Ratings of Engineering Control Methods[1]

	OAAB	CRMM w/High Lift	SATR	LVWS	HPWJ - Closed Loop	HPWJ	VAB
Worker Dust Control	5	5	2	1	1	1	2
Environmental Dust Control	5	2	2	1	1	1	2
Waste Generation	5	2	2	4	1	2	2
Productivity	1	2	5	2	2	2	5
Capital Equipment Costs	2	5	1	3	5	3	3
Cost per Square Foot of Cleaning	2	3	4	3	2	1	4
Surface Cleaning Capabilities	1	1	3	1	3	3	1

Suitability of Methods for Tasks

There are a wide variety of surface preparation tasks faced by a shipyard painting department. Not all of the dust control methods are as well suited to each task. A qualitative assessment is given below in Table 18 presenting the ratings of methods based on efficiency of the method in protecting a worker.

1 An overall rating is not computed because the optimum system to select depends upon the relative importance of the parameters listed.

Table18: Ratings of Methods Based on Efficiency for Worker and Environmental Protection

Task Description	Suggested Best Method	Suggested Alternate Method
Total Removal of Hull Coatings	CRMM*	LVWS
Partial Removal of Hull Coatings	HPWJ	LVWS, CRMM
Cleaning of Tanks	CRMM**	HPWJ, LVWS
Deck Cleaning	CRMM***	None
Weld Clean-Up	HPWJ	LVWS, VAB
Interior Space Touch-Up & Repair	SATR	None

* The suggestion to use CRMM for total removal of hull coatings is based on reductions in nuisance dust levels.
** As described in NSRP Report 0387.
*** Note that here CRMM refers to portable wheel blasting equipment, generally preferred for these tasks.

Overall Recommendation for Hazardous Dust Engineering Controls

The overall recommendation for hazardous dust engineering controls demands a balance of three factors; economics, task suitability, and ability to protect workers and/or the environment. Based on the results of our research the highest overall recommendation for tasks suited to HPWJ goes to this method. It provides a high level of protection for workers and the environment. The equipment costs and production rates are competitive with abrasive blast cleaning. Where there is a need to create a profile on the surface of the steel it is suggested that either LVWS or CRMM blasting be explored. In the event that the dust to be controlled is a hazardous dust, the recommendation would go to CRMM on the basis of lowest volume of waste generated for disposal. Note that CRMM requires improved ventilation and the use of enhanced PPEs, to ensure protection of the worker while removing paints containing hazardous metals. In interior spaces or state rooms where small area touch-up and repair is required, the use of power tools with appropriate PPEs and engineering controls is recommended. Users should recognize that there is still between a 1 in 5 and 1 in 10 likelihood of exceeding a PEL with SATR tools, based on the industry air sampling data.

Other Benefits of Hazardous Dust Exposure Control

Less easily quantified benefits of hazardous dust control do result from the implementation of the concepts and methods described in this report. First, the provision of a standard method of recording and reporting data on dust emissions provides shipyards with a valuable tool. Shipyards will be able to assess the effectiveness of a method of engineering control on their process and productivity by comparing newly entered data with historical background data. Second, the use of engineering controls to improve working conditions for the operator also has the beneficial result of improving working conditions for the surrounding workforce. This is likely to cause improvements in worker efficiency and morale.

Overall Implementation Impact

Introducing new engineering controls represent a change to the standard process for ship painting and cleaning. This type of change is often viewed as guaranteed to increase costs of construction. This project has identified hazardous dust control methods that, when properly applied in a shipyard setting, can result in minimal cost impact. This is due to the offsetting factors of equipment costs versus regulatory compliance cost for special training, monitoring, etc.

CONCLUSIONS AND RECOMMENDATIONS

Summary of Technical Review of Alternate Methods

The project included a review and analysis of the technical and trade literature, compilations of data from US shipyards and field evaluation of selected systems. In addition, a workshop was held to provide input and participation by shipyard personnel and other industry experts into the review and selection process.

Review of the Technical Literature

Conventional abrasive blasting, which is by far the most productive and effective technique for preparing steel substrates for painting, has several advantages to shipyards. It is in widespread use, the equipment needed is widely available, and there is considerable familiarity with the use of the method. However, abrasive blasting produces large volumes of dust and large quantities of waste materials, these may present disadvantages from a health and safety perspective.

- The level of airborne dust may exceed the exposure limits set by OSHA and impair the health and productivity of exposed workers.
- The dust may contain lead, cadmium, chromium or other regulated and potentially toxic heavy metals.
- The waste may contain leachable (soluble) heavy metals which and become classified as hazardous waste. This would significantly increase the cost of disposal.
- There are also reasonable concerns with controlling nuisance dusts and respirable particulate emissions in the surrounding community to maintain conformance with the Clean Air Act regulations.

The major engineering control approach to reducing the dust are as follows:

- Enclosures to contain the blast cleaning operation.
- Localized containment of the blasting operation.
- Alternate surface preparation methods that reduce or eliminate dust and the debris.

Enclosures to Contain the Blast Cleaning Operation

The types of containments used to control dust emissions from abrasive blasting in a shipyard setting f" into four general classes. These represent different design approaches.

- Type I - Modular containment "box" either on deck or on a mobile platform with recyclable metallic media.
- Type 2 - Containment system on a rigid platform hoist on the side of the vessel, with the use of recyclable media.

- Type 3 - Total containment of a dry-dock or work area with tarpaulins or other enclosure media, with or without the use of recyclable abrasive media.
- Type 4 - Partial containment, involves limited restraining of emissions using flexible tarpaulins, positioned to capture dust and abrasive debris at the end of a dry-dock or work area.

The use of containments is often accompanied by the use of recyclable media. Using mineral abrasives in any but the largest containments will result in excessive dust build-up, reduced visibility and hence reduced production. Containments of the first two types are particularly well suited to situations in which hazardous materials are being removed and there is a need to control environmental emissions. In such instances the use of recyclable metallic media greatly reduces the cost of waste disposal.

Most containments in use today are designed to meet the requirements of SSPC-Guide 6, "Guide for Containing Debris Generated During Paint Removal Operations." As such, these containments will meet (and may exceed) the ANSI requirements for ventilation of an abrasive blasting workspace. The ANSI ventilation requirements call for 60 feet per second downdraft, or 100 feet per second cross draft ventilation speeds. These ventilation speeds are only geared to ensure visibility in such a workspace. One of the containments studied in this project provided ventilation of between two to four times those required by ANSI. Even with such improved ventilation, worker protection is uncertain, PELs might be exceeded when removing hazardous materials so enhanced PPEs or administrative controls are required. If hazardous materials are being removed with such a containment then added costs for worker and workplace monitoring will be incurred. Containments are well suited to protecting workers outside of the containment from exposures, but overall designs as observed in the field require additional improvement to protect the blaster.

Localized Containment of the Blasting Operation

This entails producing a vacuum shroud around the blast impact area to entrain dust and spent debris. When performing properly this technique is capable of reducing the exposure to both workers and to the general environment. Such systems have been used extensively in large semi or fully automated operation at shipyards, for instance in deck coating removal or hull cleaning operations. (These systems are adaptations of rotary wheel blasting equipment using metallic media). More recently the technique was adapted for use with conventional air abrasive blasting equipment. Early models were limited to large regular shapes or flat sections. Modem units are equipped with various tools to allow use on complex configurations. The Vacuum Abrasive Blasting method is relatively slow. Speed of operation is low because, like any vacuuming system one needs to exert force to achieve a seal on the working surface. Productivity is relatively low as workers become easily tired through maintaining the seal, and because the hand held equipment is weighty.

Alternate Surface Preparation Methods That Reduce or Eliminate the Dust and Debris

A variety of alternate methods have been developed that reduce or eliminate dust and debris from surface preparation activities. Examples include:

- Wet Abrasive Blasting
- Pressurized Water Jetting
- Hand Held, Vacuum Enshrouded Mechanical Tools

Wet abrasive blasting has been available as technique to reduce dust emissions during blasting for nearly two decades. Recently the technique was enhanced through the introduction of a blasting unit (Torbo™) which greatly reduces the volume of water needed to entrain dust. Data from our study shows that this method improvement has clear benefits in dust control and emission reduction. Furthermore, this low volume water slurry blasting method results in a more easily handled waste product, the dust entraining water evaporates rapidly. This overcomes the primary objection to early incarnations of this method, which resulted in a sticky cake like waste media.

Wet abrasive blasting is only suited to the use of mineral abrasives. Waste volumes are equal to those from air abrasive blasting. Wet abrasive blasting is typically less productive than air abrasive blasting.

Pressurized Water Jetting is a technique of relatively recent adoption for production purposes. The technique can be used at a very wide range of water pressures. Most production work is performed from 10,000 to 35,000+ PSIg and the technique is then called High or Ultra High Pressure Water Jetting, (HPWJ or UHPWJ`). HPWJ exhibits strong attributes for dust suppression. The volume of waste produced with HPWJ depends on the manner in which waste water is handled. Water use rates can run as low as a gallon per minute, though use rates of between two and three gallons a minute are typical. The US Navy has examined the use of HPWJ in conjunction with water collection, recycling and reuse. Under such conditions the total volume of waste is the lowest of any method, consisting solely of the removed coating. The primary weaknesses of HPWJ are its inability to produce a profile or productively remove tight rust or paint and the need to contain, treat and dispose of the water. HPWJ is also not well suited to some tasks. In tank interior blasting, for example, high moisture levels build up, misting ensues and visibility becomes an issue. Furthermore HPWJ cannot create typical profiles on steel, and may result in unacceptable flash rusting levels, requiring reblasting with HPWJ or conventional media.

Vacuum enshrouded mechanical tools are useful in Small Area Touch-Up and Repair (SATR). These tools are capable of preventing dust emissions to the environment and the worker, though such protection is not always afforded. In part this may be because of the failure to maintain an adequate seal with the equipment on the working surface. In instances where these tools are used for removal of hazardous materials enhanced worker protection is recommended. This technique can result in very low volumes of debris compared to air abrasive blasting. Productivity with this method is low (though comparable to Vacuum Abrasive Blasting). These tools are well suited to use in cramped quarters, and in delicate areas where use of other methods might result in damage to shipboard equipment.

Selection of Methods for Field Evaluations

A methods selection workshop was held, preceded by a conference, to identify candidate methods for field evaluation. Shipyard representatives described the range of generated dusts and hazardous dust control methods used in the marine industry. Several presentations were also made by industry experts and researchers on new or evolving engineering controls for hazardous dust exposure limitation. The problem solving groups selected the following methods:

- High Pressure Water Jetting (HPWJ).
- Low Volume Water Slurry Blasting (LVWS)'.
- Vacuum Assisted Blasting (VAB).
- Small Area Touch Up and Repair (SATR).
- Containment with use of Recyclable Metallic Media (CRMM).
- Open Air Abrasive Blasting (OAAB) (standard control method).

The workshop and conference was deemed a successful method for providing shipyard input and direction on an NSRP Project. Our recommendation is that a similar means to enhance shipyard involvement and project participation be made part of any project requiring field trials. A two-fold course of action was suggested from the workshops, acquisition of existing data on the selected methods from participating yards, and field evaluations of these trials.

Results and Conclusions from Data Collection and Analysis

General Approach

This study examined the effectiveness of several engineering controls and surface preparation methods for dust control during surface preparation work in shipyards. The data collected during the field evaluation phase of this work has documented the airborne dust and contaminant exposures measured during surface preparation in several shipyards, across the United States, on military and commercial vessels.

Database Developed

A process was developed for collecting, storing, organizing and retrieving data on shipyard surface preparation engineering controls. This was designated the hazardous airborne dust database (HADD). It consisted of a standardized data form that requested information on the type of job, the method of surface preparation, the productivity, the type of engineering control (e.g., ventilation, dust control), the type of PPE, and the results of monitoring to the worker breathing zone for a wide array of hazardous airborne dusts.

Air monitoring data provided by participating shipyards and entered into the HADD did not typically provide sufficient technical process information to evaluate the relationship between specific variables and the control of airborne dust. This is a significant finding of this study. Variables such as nozzle diameter, supply air pressure, abrasive particle size, concentration of toxic materials in the dried paint film (Pb, Cd, Cr, etc.), ventilation equipment in place and proximity to other contaminant producing operations were rarely documented with the air sampling data. Better correlation between these performance data and the generation or control of resulting airborne contaminant concentrations will be a crucial step for shipyards to implement effective dust control procedures for modem surface preparation work.

Airborne Contaminants Present Potential Hazards

Many airborne contaminants may be found during shipyard surface preparation work. This study identified 39 contaminants that warranted evaluation by shipyard health and safety professionals during the past 5 years. The ones most commonly observed are lead (627 of 2,478), cadmium (375 of 2,478), chromium (347 of 2,478) and copper (214 of 2,478). Total dust (e.g., nuisance dusts) and respirable dust (68 of 2,478) are also of concern. These data indicate that the value of effective dust control will yield protective benefits far beyond the immediate high profile issues (such as lead) in the public eye.

Engineering Controls for Surface Preparation: Effectiveness in Reducing Dust

Based on the workshop recommendations five dust control systems were selected to be evaluated as an alternative to the conventional method of open air abrasive blast cleaning.

These are as follows:

- High Pressure Water Jetting (HPWJ).
- Low Volume Water Slurry Blasting (LVWS).
- Vacuum Assisted Blasting (VAB).
- Small Area Touch Up and Repair using vacuum shrouded power tools (SATR).
- Containment with use of Recyclable Metallic Media (CRMM).
- Open Air Abrasive Blasting (OAAB) (standard control method).

For each of these methodologies, data from the HADD were analyzed and a field evaluation was undertaken. For each of the six methods, the frequency of exceeding the PEL was computed for cadmium and lead, the metals most frequently detected. The PELs were exceeded about 35 to 40% of the time for the dry blast cleaning methods (CRMM and OABB). For SATR, the PELs were exceeded about 15 to 17% of the time. The wet methods (LVWS and HPWJ) showed essentially zero exceedances.

Engineering Controls for Surface Preparation: Overall Assessment
In addition to dust control there are several other factors that would influence the decision to select an alternate surface preparation/engineering control system, these include:

- Degree of Worker Protection - Worker/Blaster, Breathing Zone
- Degree of Worker Protection - Surrounding Work Area and Community
- Quantity of Waste Produced
- Productivity
- Cost for Capital Equipment
- Cost of Cleaning (per Square Foot), and Surface Cleaning Capability.

Each of the six methods was ranked in each of these categories. The relative merits of each are summarized as follows-

- **OAAB** Most productive and best quality surface, but produces unacceptable amount of uncontained dust and debris. Also generates very large amounts of waste which often requires specialized and costly disposal.
- **CRMM** High productivity with highest quality surface achievable, reduces waste by recycling, reduces dust hazard, requires significant capital expenditure and results in relatively high cost per square foot.
- **SATR** Reduces dust and waste, but at greatly reduced production rate and decreased surface quality, cost relatively high per square foot.
- **LVWS** Greatly reduced waste and dust with a slight decrease in productivity, relatively high volume of waste requiring disposal.
- **HPWJ** Greatly reduced waste and dust, relatively high productivity and low cost persquare foot, but gives reduced surface quality.
- **VAB** Reduced dust and waste, high surface quality, significant reduction in production rate and increase in cost per square foot.

A set of guidelines was developed for each method describing the principles of operation, equipment and components needed, operating parameters (e.g., pressures and volumes of water, abrasive), reuse capability, safety equipment and expected productivity. These guidelines are shown in Appendix (X) of this report.

Cost model developed

A model was developed to analyze the cost for surface preparation methods used at shipyards. The cost components identified were: equipment costs (amortized over five years), operating costs, material costs (e.g., abrasives and other consumables), labor costs for surface preparation, and cost for waste disposal. Detailed data were available for two of the methods (OAAB and CF1VM. These costs were analyzed on the basis of $ per sq. ft. The costs were significantly influenced by the number of re-use cycles and whether the waste was hazardous. In order to compare these costs with those of alternate methods, additional data are needed on the equipment purchase and maintenance costs, expected use per year, productivity, and cost for setting up a specific worker protection program (e.g., training and implementing).

RECOMMENDATIONS

Upon review of the findings from the Technology Evaluation phase of this study, the following recommendations are provided for future follow up action:

Improve collections and management of health and safety data

Shipyards are advised to implement better integration of air sampling (Health and Safety) information and process control (Production) data. Since this information is often collected by different people, working for different Departments or different contractors, these key data elements never seem to meet. Shipyards should take a "big picture" view of surface preparation operations and use their air sampling data (already required for OSHA compliance) as a means of measuring the effectiveness of new equipment, materials, or process changes. A suggested format and database for this purpose has been developed under this project, as presented in Figure 1.

Evaluate alternate Systems to meet the specific shipyard needs

Focus dust control follow up efforts on abrasive recycling and promising methods such as LVWS and HPWJ for which limited data is available in the HADD database. As demonstrated by the air sampling results collected for this study, Open Air Abrasive Blasting and Containment with Recyclable Metallic Media generated the highest worker exposure to hazardous dust levels (e.g. lead). These are also the methods which account for the greatest volume of production in current shipyard surface preparation operations. High Pressure Water Jetting is finding increased use in shipbuilding and ship repair work. One might expect Low Volume Water Slurry Blasting to do the same, based on our preliminary results. Of the traditional blasting methods we recommend significant attention be given to studies of containment systems with improved ventilation characteristics.

Collect, compile and exchange information

NSRP and shipyards are encouraged to expand efforts to compile new monitoring data and information on the results from applying engineering controls on shipyard surface preparation activities. Using a consistent data collection format, such as the model developed for this study, will ensure the comparative value of the information. Sharing of additional data and knowledge will allow yards to select and implement systems with greatly increased likelihood of predictable results for cost effective protection of shipyard personnel and of the local environment.

Supplementary Materials

Certain materials generated during the course of this project were previously submitted to the NSRP as interim deliverables. These items are described below. Readers of this report who are interested in receiving a copy of these items are urged to contact the NSRP Program Management for copies of these reports.

Deliverable Item 1 - Technology Review

A comprehensive literature search was conducted that interrogated electronic databases specializing in engineering, health and safety sciences, and industrial coating journal article abstracting. To supplement this effort an exhaustive search was also made of the SSPC technical libraries, our conference proceedings, and of back-issues of the Journal of Protective Coatings and Linings. Articles were ranked for relevance based on content descriptions and keyword occurrences. Articles featuring information about dust emission control technologies for surface preparation and coating were given highest rankings. Those citations with general health and safety information concerning engineering or administrative controls and for PPE measures were also given high rankings. To achieve this the summary article information was entered into a custom database, then each entry was searched for the occurrence of specific keyword combinations. The higher number of instances of a keyword combination the higher the ranking. The types of keyword combinations used included: coating or paint and/or lead and/or chrome and/or chromate and/or dust emissions and/or dust control and/or worker exposure. In this manner from over 1200 citations retrieved we were able to identify around 120 highly relevant articles.

The articles and reports of greatest relevance were retrieved, reviewed, and summarized in an annotated bibliography. From our review process was generated a literature review report which identified the range of dust emission and control problems in the protective coating industry, and issues specific to the shipbuilding and ship repair industry. The literature review provides a report on the state-of-the-art for worker protection against hazardous dusts during surface preparation and coating work. Major conclusions from the search of the technical literature are presented earlier in this report. This deliverable includes the full written report, the annotated bibliography, and the electronic databases with all the original citations and their relevance ratings recorded.

Deliverable Item 2 - Results of Shipyard and Industry Survey

A second information retrieval exercise involved a shipyard and industry survey. Our survey used a mixture of phone surveying and a written response document. Respondents were asked to give details on the type of dust control problems they face in surface preparation and coating tasks. The surveys were detailed. Requests were made for information on instances of control of exposure to some twenty contaminants. Specific information was sought on the process conditions under which the exposure control became an issue. Information was sought on the types of engineering control methods typically used in a shipyard setting. Respondents were asked if they were willing to participate in a future conference and workshop, to examine the problem of hazardous dust control in shipyard surface preparation work. All responses were entered into a database and tallied. Our industry survey also provided information on the types of equipment required for effective dust control in a shipyard setting.

This deliverable provides an analysis of the frequency with which different contaminants are found in surface preparation and coating work. The range of different engineering or other control measures used to control worker exposure in a shipyard setting is described. Availability and descriptions of dust control equipment are provided. The deliverable includes an electronic version of the database used to summarize and tally response information.

Deliverable Item 3 - Proceedings of the Conference & Workshops on "Controlling Hazardous Airborne Dusts in Shipyard Preparation and Coating Operations."

This deliverable is a comprehensive description of the conduct of the conference and workshops. The conference included presentations from industry experts and shipyard surface preparation or safety professionals on hazardous dust control methods. The deliberations of the workshops are summarized. These workshop deliberations also lead to the outlining of a refined workplan for field evaluation of the engineering control methods. In addition this workshop was the point in the project at which our participating yards were identified.

The deliverable is presented in three parts:

- Complete presentations from the nine speakers, including copies of slides when available.
- A description of the workshops.
- A description of the final workplan.

Deliverable Item 4 - Report on Evaluation of Engineering Control Methods & Deliverable Item 5 - Report on Evaluation of PPE Measures

These two deliverables were provided in a combined report. The content of the report summarized the following activities:

- Collection and analysis of participating shipyard data on engineering control and -PPE use, and
- Collection of data on engineering control use from shipyard visits.

The shipyard data reported on engineering control use was placed in a custom database termed the Hazardous Airborne Dusts Database, or HADD. The HADD database provides for shipyards a means to compare engineering control method use. The HADD also gives shipyards a uniform means for recording their own data on engineering controls and the degree of protection afforded workers by their use.

Appendices

APPENDIX 1. Guidelines on Engineering Control Capabilities

PROCESS CAPABILITIES OF EXAMINED SURFACE PREPARATION METHODS

This section describes the capabilities of each method in terms of achievable finish conditions. Discussion is also given to the viability of each method in meeting the needs of typical shipyard surface preparation tasks.

Reference Standards

The following reference standards are used to describe the capabilities of each method:
SSPC-SP I - Solvent Cleaning
SSPC-SP 3 - Power Tool Cleaning
SSPC-SP 5 - White Metal Blast Cleaning
SSPC-SP 6 - Commercial Blast Cleaning
SSPC-SP 7 - Brush Off Blast Cleaning
SSPC-SP 10 - Near White Metal Blast Cleaning
SSPC-SP 11 - Power Tool Cleaning to Bare Metal
SSPC-SP 12 - High Pressure Water Jetting
The following visual references are used to provide examples of expected finish quality:
SSPC-Vis 1-89 - Visual Standard Reference Photographs (Abrasive Blast Cleaning)
SSPC-Vis 3-93 - Visual Standard Reference Photographs (Hand & Power Tool Cleaning)
SSPC/NACE Draft Visual Reference Photographs for High Pressure Water Jetting

Reference Tasks

The following tasks are common in a shipyard setting and are used as measures of a methods suitability to meet shipyard needs.

1. Partial Removal of Hull (Anti Fouling) Coatings
2. Total Removal of Hull (Anti-Fouling/Anti-Corrosive) Coatings
3 Refinishing of Interior Spaces - Bilge or Ballast Tanks
4. Deck Coating Removal/Refurbishment
5. Refinishing of Weld Areas

Method 1 - High **Pressure Water** *Jetting*

Surface Texturing

High pressure water jetting will not provide a textured clean surface typical of that provided by abrasive blast cleaning or other mechanical methods of paint removal. Any existing profile on the metal is retained by this method.

Surface Quality

The SSPC-SP 12/NACE No. 5 Specification defines four levels of cleanliness, all are achievable with high pressure water jetting. The four levels of cleaning are:

WJ-I - This level of cleaning is close in character to SSPC-SP 5, it entails total removal of all prior existing paint, rust, and millscale.

WJ-2-This level of cleaning also removes all prior existing paint, rust, and millscale. It is permitted to retain on the surface randomly dispersed stains over 5% of the surface. This level of cleaning is comparable to SSPC-SP 10 Near White Metal Blast Cleaning.

WJ-3-This level of cleaning differs from WJ-2 in allowing a greater amount of staining on the surface, up to one-third of the surface may exhibit such staining. This level of cleaning is comparable to SSPC-SP 6 Commercial Blast Cleaning.

WJ-4-This level of cleaning is similar to SSPC-SP 7 in that only loose material is removed from the surface.

Note 1:

Stains are caused by minute particles of prior existing materials - the particles are too small to be seen by the naked eye.

Note 2:

Millscale can be removed by longer dwell times with ultra-high pressure water jetting. For all practical purposes high pressure water jetting is not used for millscale removal. A true WJ-3 through WJ- 1 surface is achieved in practice on surfaces which were previously descaled by another mechanical cleaning method.

Note 3:

In some cases the finished metal surface will exhibit flash rusting. The compatibility of a coating with such a flash rusted surface is a matter on which yards should seek coating manufacturer advice. Guidelines for acceptable flash rusting are under development as part of the draft SSPC/NACE Visual Reference Photographs for High Pressure Water Jetting.

Task Compatibility

High pressure water jetting shows the following task compatibility:

Partial Removal of Hull (Anti Fouling) Coatings

Hull coating removal is one of the largest current applications of this method in the shipbuilding industry. Partial coating removal requires operator skill to remove only a set level of coating material. There is a deficiency in the current written definition for WJ-4. The practice during ship repair and refurbishment is to accept a set level of retained coating. The definition for WJ-4 does not allow such a refinement, it stipulates removal of loose material with no regard to the percentage of original coating retained on the surface. Currently this disconnect between industry practice and consensus standard is addressed by agreement between vessel owner and shipyard.

Total Removal of Hull (Anti-Fouling/Anti- Corrosive) Coatings

As mentioned above total hull coating removal is a common application for this method in the ship repair community. Any surface ranging from WJ-3 to WJ- 1 is achievable with high pressure water jetting.

Refinishing of Interior Spaces - Bilge or Ballast Tanks

Currently the footprint of the high pressure water jetting equipment makes its use in close quarters cumbersome. This deficiency may be addressed by equipment developments such as that of NAVSEA using the Pratt & Whitney System.

Deck Coating Removal/Refurbishment

Currently high pressure water jetting is employed less in this function than in hull coating removal tasks. Typically this task is performed with portable wheel-blasting equipment. In principal deck coating removal is a viable application for high pressure water jetting. This application is similar to the task of removing thick rigid or elastomeric coatings in general industry. This is due to the ability of high pressure water jetting to undercut and lift large sections of coatings.

Refinishing of Weld Areas

High pressure water jetting would also seem suited to preparation of weld seams prior to painting. No surface profile would be created, but the method will remove weld spatter and slag from the surface. The method is incapable of contouring the weld seam to optimize coating adhesion.

Reference and Contacts List

Lydia Frenzel 209-267-0992
Rick DuPree, UHP Projects, Yorktown VA 800-982-3011
Cavitech, Guy Leber, Kennesaw, GA 770424-0015
WOMA, Frank Sharwat, Everett WA 800-258-5530
Dennis McGuire @ AMCLEAN

Method 2 - Low Volume Water Slurry Blasting

Surface Texturing
This method uses a combination of water (for dust control) and abrasive (for mechanical cleaning). Using abrasive, the method is capable of producing any specified profile. The profile produced is dependent on the abrasive mix and operating pressures.

Surface Quality
The method alleviates one of the problems with earlier wet abrasive blasting methods, that of flash rusting. The low volume of water is in contact with the surface for a limited period of time. Drying of the surface occurs very quickly. The method also alleviates one of the other problems associated with traditional wet abrasive blasting, that of clean-up of waste material. Unlike earlier wet abrasive blasting there is little caking of spent abrasive. The low volume water slurry blasting leaves far less residue on the steel surface than traditional wet abrasive blasting methods. Most residues are easily removed by blow-down after coating removal.
Low volume water slurry blasting can provide any level of cleaning from SSPC-SP 7, Brush-Off Blast Cleaning, through to SSPC-SP 5, White Metal Blast Cleaning.

Task Compatibility

Partial Removal of Hull (Anti Fouling) Coatings
This method is compatible with hull coating removal tasks.

Total Removal of Hull (Anti-Fouling/Anti- Corrosive) Coatings
This method is compatible with hull coating removal tasks.

Refinishing of Interior Spaces - Bilge or Ballast Tanks
This method is compatible with refinishing of tanks and other interior spaces. There will be a need for clean-up of waste abrasive.

Deck Coating Removal/Refurbish ment*t*
Typically this task is performed with portable wheel-blasting equipment.

Refinishing of Weld Areas
This method is compatible with the task of refinishing of welded areas.

Method 3 - Vacuum Assisted Blasting

Surface Texturing
This method is fully capable of providing any specified surface texture. The surface profile produced is dependent on abrasive mix and operating pressures.

Surface Quality
This method can achieve any of the levels of cleaning defined by SSPC-SP 7 through SSPC-SP 5.

Task Compatibility

Partial Removal of Hull (Anti Fouling) Coatings
This method is compatible with hull coating removal tasks.

Total Removal of Hull (Anti-Fouling/Anti-Corrosive) Coatings
This method is compatible with hull coating removal tasks.

Refinishing of Interior Spaces - Bilge or Ballast Tanks
This method is compatible with refinishing of tanks and other interior spaces. There will be a need for accommodating abrasive feed and recycling hoses. This can lead to cramping of working conditions in close quarters.

Deck Coating Removal/Refurbishment
Typically this task is performed with portable wheel-blasting equipment.

Refinishing of Weld Areas
This method is an ideal choice for the task of refinishing of welded areas.

Method 4 - Small Area Touch-Up & Repair (Power Tools)

Surface Texturing

The produced surface texture is dependent on the type of tool and media employed. The produced profile will differ in texture from that of abrasive blast cleaning methods. Needle guns will provide surfaces that have a peened texture. Abrasive media on disks or on wheels will typically yield a smoother profiled finish than that of abrasive blasting methods. Surface profile is not addressed directly in SSPC-SP 3 Power Tool Cleaning. Surface profile control is addressed in SSPC-SP 11 Power Tool Cleaning to Bare Metal. SSPC-SP 11 cleaning should not reduce existing profiles by more than one-half mil.

Surface Quality

There are two levels of cleaning defined for Power Tool Cleaning, SSPC-SP 3 and SSPCSP 11. Only loose material is removed with SSPC-SP 3 Cleaning, SSPC-SP 11 Cleaning removes all material from a flat surface. SSPC-SP 11 permits material to be retained at the bottom of deformations (pits) in a steel surface.

Task Compatibility

Partial Removal of Hull (Anti Fouling) Coatings

This method has limited application for this task. It can be used for touch-up of blasted surfaces or to feather the edges of coatings cleaned by other methods.

Total Removal of Hull (Anti-Fouling/Anti-Corrosive) Coatings

This method is impractical in this application.

Refinishing of Interior Spaces - Bilge or Ballast Tanks

This method has application in conducting partial removal of material in interior spaces.

Deck Coating Removal/Refurbishment

This method is impractical in this application, except to touch up edges of areas cleaned using other techniques.

Refinishing of Weld Areas

This method is widely employed in refinishing of weld areas. It has the ability to simultaneously clean the weld zone and provide contour to the weld seam.

Method 5 - Containment with the Use of Recyclable Metallic Media

Surface Texturing
This method is fully capable of providing any specified surface texture. The surface profile produced is dependent on abrasive mix and operating pressures.

Surface Quality
This method can achieve any of the levels of cleaning defined by SSPC-SP 7 through SSPC-SP 5.

Task Compatibility

Partial Removal of Hull (Anti Fouling) Coatings .
Believed compatible with removal of copper based anti-fouling coatings. No data on compatibility with removal of organo-tin anti-fouling coatings.

Total Removal of Hull (Anti-Fouling/Anti- Corrosive) Coatings
Believed compatible with removal of copper based anti-fouling coatings. No data oncompatibility with removal of organo-tin anti-fouling coatings.

Refinishing of Interior Spaces - Bilge or Ballast Tanks
This task is not suited to the subject method.

Deck Coating Removal/Refurbishment
This task is already conducted using portable wheel blasting equipment. The equipment is a type of containment unit intended to maximize abrasive recovery and reuse.

Refinishing of Weld Areas
This task can be accomplished with the subject method, but it is believed that movements of a containment might hamper productivity.

Method 6 - Open Air Abrasive Blasting

Surface Texturing
This method is fully capable of providing any specified surface texture. The surface profile produced is dependent on abrasive mix and operating pressures.

Surface Quality
This method can achieve any of the levels of cleaning defined by SSPC-SP 7 through SSPC-SP 5.

Task Compatibility

Partial Removal of Hull (Anti Fouling) Coatings
This method is compatible with hull coating removal tasks, though local constraints on fugitive emissions of spent abrasive and paint waste may make it less attractive for use near waterways.

Total Removal of Hull (Anti-Fouling/Anti-Corrosive) Coatings
This method is compatible with hull coating removal tasks, though local constraints on fugitive emissions of spent abrasive and paint waste may make it less attractive for use near waterways.

Refinishing of Interior Spaces - Bilge or Ballast Tanks
This method is compatible with refinishing of tanks and other interior spaces. There will be a need for clean-up of waste abrasive.

Deck Coating Removal/Refurbishment
Typically this task is performed with portable wheel-blasting equipment, use of open-air abrasive blasting is possible.

Refinishing of Weld Areas
This method is compatible with the task of refinishing of welded areas.

APPENDIX 2. Productivity Impact of Engineering Controls

FACT SHEETS ON ENGINEERING & PROCESS CONTROLS EXAMINED

The research team examined several engineering or process controls to determine their viability in controlling hazardous airborne dusts.

The specific surface preparation techniques and processes examined were:

- High Pressure Water Jetting
- Low Volume Water Slurry Blasting
- Vacuum Assisted Blasting
- Small Area Touch-Up & Repair (With or Without Vacuum Retrieval)
- Containment with Use of Recyclable Metallic Media
- Open Air Abrasive Blasting

One type of personal protective equipment was also examined, the use of Type CE abrasive blasting helmets.

The following sections describe the ability of each of the surface preparation methods to provide definable levels of cleaning. Discussion is also given of the suitability of each method to meet typical shipyard surface preparation task requirements.

Each section begins with a series of fact sheets which describe in brief detail the general characteristics of each method. This material is based on submissions originally made by SSPC to the David Taylor Research Center.

These fact sheets present general information on the capabilities of each method. Expected productivity estimates are given, based on our review of current practices, the technical literature and input from suppliers, contractors and shipyard users. Productivity figures are given as ranges. The low end of the range corresponds to the highest level of cleaning achievable with the method. In the case of abrasive blasting methods this is SSPC-SP 5 cleaning. The high end of the productivity range corresponds to SSPC-SP 7 "Brush Off
Blast Cleaning."

Ranges for power too] cleaning and high pressure water jetting are qualified within their respective fact sheets.

FACT SHEET 1

ULTRA HIGH PRESSURE WATER JETTING

OPERATING PARAMETERS

General Principles

- A jet of water impacts on the surface. Pressure is moderated by user. Wide range of pressures available. High Pressure Water Jetting typically refers to cleaning with water between 25,000 to 35,000 PSIg. Abrasive can be co-injected into blasting stream.

Water Pressure

- Between 25,000 to 35,000 PSIg at the nozzle measured by in line gauge.

Attitude to Surface

- 90 ± 15° to plane. Some equipment maintains perpendicular attitude to plane.

Abrasive Consumption

- Not applicable. See Fact Sheet 2 for Wet Blasting, and for Discussion of Water blasting with injection of abrasive. Typical water consumption rates are 2-3 gal per minute.

Abrasive Mix

- Not applicable

Materials Required

- Source of potable water.

Equipment Required

—For Water Blasting. Fluid Compressor, Fluid Feed Hoses, Blast Nozzles, Deadman Switch, Separate air supply for operator. Waterproof protective gear. Wide range of fluid nozzle arrays available.

Reuse Capabilities

- Generates fluid waste stream. Fluid can be collected and screened of paint/rust debris.

Special Provisions

- High pressure water jetting will produce a surface susceptible to flash rusting. There are currently no mandatory industry standards for degree of flash rusting. The compatibility of a surface for coating is decided between coating supplier and user. Typically if excessive flash rusting is a concern the surface will be re-blasted either by abrasive or by high pressure waterjetting before coating.

Special Uses

- High Pressure Water Jetting is suggested for removal of oils/greases/dirts from a surface to be painted. Can be employed for layer by layer removal of paint materials. Can remove coatings from non-ferrous surfaces. Cannot remove scale from a ferrous surface. Useful in reducing the level of contamination of a steel surface. Cannot impart a profile to the surface. A typical use would be undercutting of lay-up composite materials or elastomeric coatings.

Recommended Safety Equipment

- Deadman Switch on Fluid Nozzle, Full Hood Respirator with Supplied Air, Steel Capped Safety boots, Safety glasses. Other Safety equipment may be required for specific operations.

Expected Productivity

- For Blasting alone. Depends on coating being removed. Depends on degree of cleaning. Removal rates are somewhat below those achieved with abrasive blasting and are in the range of 150 - 1000 sq. ft. per hour (WJ 1 - WJ4 as defined in SSPC- SP 12). These Productivity figures will decline if you take into account time
required for clean up of

debris, maintenance of recycling equipment, maintenance of working mix etc. Assume overall productivity in work session declines to 85 % of optimum.

FACT SHEET 2

LOW VOLUME WATER AIR ABRASIVE WET BLASTING

OPERATING PARAMETERS

Air Pressure

- Between 85-100 PSIg at the nozzle measured by use of Hypodermic Pressure Gauge.

Water Pressure

- 60 - 100 PSIg to the nozzle or annular ring assembly.

Attitude to Surface

- 90 ±15° to plane. Some Equipment maintains perpendicular attitude to plane.

Abrasive Consumption

- Varies with abrasive. Typical consumption rates are 3 - 8 lb. per square foot for mineral abrasives.

Abrasive Mix

- Depends on required surface profile.

Water Consumption

- This technique uses lower volumes of water than earlier wet abrasive blasting techniques.

Materials Required

- Advisable only to use Mineral or Slag Abrasive, Steel or metallic abrasives will rust.

Equipment Required

- For Blasting. Blast Pot, Compressor, Blast Hoses, Blast Nozzles, Deadman Switch, Separate air supply for operator, Anti-Static grounding for Blast Equipment when working around volatile organic materials, fuels etc. Clean (potable) Water supply.

Special Provisions

- Reuse of abrasive requires thorough drying prior to separation. Some users have experienced considerable difficulty in manipulating the waste abrasive cake resulting from this type of blasting. This specific method claims to overcome concerns about abrasive caking. Earlier wet abrasive blasting methods produced conditions under which flash rusting might occur. This method claims to produce a very dry surface immediately after blast cleaning.

Special uses

- Wet abrasive blasting is employed for two reasons, to reduce dusting, or to lower ionic contamination on a surface to be painted. Dust suppression may be desirable if one is working around delicate equipment. Studies' by SSPC have shown wet abrasive blasting to be somewhat efficient in dust suppression, but less effective in reduction of saline surface contamination. Dust suppression was most efficient when the water was injected into the stream of abrasive, least effective if sprayed into abrasive stream from an annular ring assembly.

Recommended Safety Equipment

- Deadman Switch on Abrasive Nozzle, Full Hood Respirator with Supplied Air, Steel Capped Safety boots. Other Safety equipment may be required for specific operations, for instance in removing hazardous materials in confined areas air flow must be maintained to prevent build up of air borne contaminants.

Expected Productivity - For Blasting alone

Depends on coating being removed. Depends on degree of cleaning. Removal rates are between 250 - 1700 sq. ft. per hour peak productivity or 60-90 % that of unconfined air abrasive blasting when removing millscale or rust alone. Removal of paint or coating films is less productive, thick films such as coal tar epoxy might be removed at less than 60 sq. ft per hour, thin or severely brittle films such aged epoxy or alkyds can be removed at up to 250 sq. ft. per hour

FACT SHEET 3

VACUUM ABRASIVE BLASTING

OPERATING PARAMETERS

General Principles

- Abrasive blast cleaning with near instantaneous recovery of media and debris at the blast nozzle site using a vacuum take off.

Air Pressure

- Between 85-100 PSIg at the nozzle measured by use of Hypodermic Pressure Gauge.

Attitude to Surface

- 90 ± 15° to plane. Some Equipment maintains perpendicular attitude to plane.

Abrasive Consumption

- Varies with abrasive. Typical consumption rates are 3 - 8 lb. per square foot for mineral abrasives, without reuse of abrasive; abrasive reuse could significantly improve this figure.

Abrasive Mix

- Depends on required surface profile.

Materials Required

- Steel Grit or Steel Shot recommended can use Reusable Mineral or Slag Abrasive.

Equipment Required

- For Blasting. Blast Pot, Compressor, Blast Hoses, Special Blast Nozzles with Vacuum shrouds, Deadman Switch, Separate air supply for operator, Anti-Static grounding for Blast Equipment when working around volatile organic materials, fuels etc. For Recycling of Abrasive
- Cyclone separator, filter apparatus to collect fines, abrasive debris. Vacuum shrouds to collect used abrasive for recycling or some other custom built collection device.

Reuse Capabilities

- Steel Grit Steel Shot - High 22 % loss on each reuse of material. Approximately fifty recycles of material before complete replenishment of working mix. Manufacturers of steel abrasive claim that under ideal conditions reuse should be based upon a 0.5% loss per cycle. Mineral/ Slag Abrasive Ranges from a high of five to ten times reuse for selected mineral abrasives such as aluminum oxide or garnet to a low of 1.5 times reuse for boiler/copper slag materials.

Special Provisions

- Reuse of abrasive requires maintenance of a correct working mix. Particularly important for recycled steel abrasives. Weight of vacuum shroud attachment is high 3 20 lb. Increases worker fatigue. Vacuum shrouds useful on plane surfaces, complex shapes may interrupt vacuum seal, allowing release of abrasive. Vacuum should be placed in direct contact with surface at all times.

Special uses

- Vacuum Blasting is employed for two reasons, to reduce the volume of waste/ dust emissions, or to capture and separate abrasives from hazardous (paint) materials.

Recommended Safety Equipment

- Deadman Switch on Abrasive Nozzle, Full Hood Respirator with Supplied Air, Steel Capped Safety boots. Other Safety equipment may be required for specific operations, for instance in removing hazardous materials in confined areas air flow must be maintained to prevent build up of air borne contaminants. High Efficiency Particulate Air filters may be needed to control dust emissions from abrasive separation unit if coating can create hazardous dust.

Expected Productivity - For Blasting alone.

Depends on coating being removed. Depends on degree of cleaning. Removal rates are between 100 - 450 sq. ft. per hour peak productivity. Over a typical shift typical removal rates may average 40 - 300 sq. ft. per operator. These Productivity figures will decline if you take into account lost time due to fatigue, maintenance of recycling equipment, maintenance of working mix etc. Assume overall productivity in work session declines to 85 % of optimum.

FACT SHEET 4- Small Area Touch-Up and Repair

POWER TOOL CLEANING

OPERATING PARAMETERS

General Principles

- Air or Electric driven tools are used to achieve an SSPC SP 3 level of cleaning.

Power Tools

- Both Electric and Pneumatic Power Tools available. They fall into seven classes, Needle Guns, Disc or Rotary Sanders, Power Wire Brushes, Rotary Power Flaps with embedded Steel Shot, ("Roto-Peen"), Descaling Hammers, Scarifiers, and Cylindrically Mounted Rotary Coated Abrasive Discs. Only certain of these will achieve an SSPC SP 11 finish, please consult the specification for further details on the capabilities of distinct classes of power tools.

Air Pressure

- Variable at tool.

Attitude to Surface

- 90 ± 15 degrees to plane. Some Equipment maintains perpendicular attitude to plane.

Abradant Type

- A wide variety of types of removal media are available. These range from abrasive discs to power wire brushes, and include needles, descaling hammers, and shot coated rotary flaps for roto-peen devices.

Equipment Required

- Compressor, Deadman Switch, Anti-Static grounding for Equipment when working around volatile organic materials, fuels etc.

Recommended Safety Equipment

- Steel Capped Safety boots. Other Safety equipment may be required for specific operations, for instance in removing hazardous materials in confined areas air flow must be maintained to prevent build up of air borne contaminants. High Efficiency Particulate filters may be needed to control dust emissions.

Expected Productivity

- Removal rates are between 50-80 sq. ft. per hour peak productivity to achieve SSPC SP 3 Cleaning.

Lower Rates on the order of 10-30 sq. ft. per hour apply for removal of thin deteriorated films to achieve an SP 11 Cleaning, thicker films can also be cleaned to bare metal but rate of cleaning may be in low double figures per hour.

FACT SHEET 4A - Small Area Touch- Up and Repair

VACUUM POWER TOOL CLEANING

OPERATING PARAMETERS

General Principles

- Vacuum Power Tool Cleaning achieves either an SSPC SP 3 or an SSPC SP 11 level of cleaning. The devices are fitted with vacuum take-off attachments to collect dust and debris.

Power Tools

- A variety of power tools are available. Presently only Needle Guns, Rotary Scarifiers, Rotary wheel flap tools & Disc Sanders can be fitted.with effective vacuum take-offs.

Power Source

- Either Air Driven or Electric

Air Pressure

- Variable pressure to tool allows control of speed.

Electric Tools

- Speed controlled at tool itself

Attitude to Surface

- 90 ± 15° to plane. Some Equipment maintains perpendicular attitude to plane.

Tool Consumption

- Varies widely with manufacturer. Some cheaper tools generally last for one shift, then are thrown away. Medium price tools may last for a work week before needing rework on the tool mechanism. Highest quality Vacuum Power Tools are of all stainless self cleaning construction, giving effective infinite life. Only replaceable item are the needles themselves, required replacement for this item is once every 2 -3 weeks.

Materials Required

- Special Abrasive Media such as coated abrasive discs or mechanical cleaning items such as needles or shot coated roto-peen flaps. Abrasive media, such as discs may need to be changed every couple of hours, needles may need to be replaced once a week

Equipment Required

- Compressor, vacuum take-off, pressure hoses, deadman switch, separate air supply for operator, anti-static grounding for equipment when working around volatile organic materials, fuels etc. For Recovery of Debris: Filter apparatus to collect fines, abrasive debris. Vacuum shrouds to collect waste paint for recovery or other custom built collection device.

.Special Provisions

- Weight of vacuum attachment/power tool combination can be high 3 20 lb. Increases worker fatigue. Vacuum shrouds useful on plane surfaces, complex shapes may interrupt vacuum seal, allowing release of abrasive. Vacuum should be placed in direct contact with surface at all times. Choice of equipment may depend as much on efficiency of recovery as efficiency of production.

Special uses

- Vacuum Power Tool Cleaning is employed for two reasons, to reduce the volume of waste/ dust emissions, or to capture and separate hazardous (paint) materials.

Recommended Safety Equipment

- Respirator with Cartridge Filters, Steel Capped Safety boots. Other Safety equipment may be required for specific operations. High Efficiency Particulate Air filters may be needed to control dust emissions from paint debris separation unit.

Expected Productivity

- Depends on coating being removed and degree of cleaning. Removal rates are typically about 20-40 sq. ft. per hour peak productivity for an SP 11 surface; the rates are approximately 50-200 sq. ft. per hour for an SP 3 cleaned surface.

Tool Cost

- Lowest Priced Tools $ 300 - 400, e.g. Needle Guns, Roto-Peen, Disc Sanders.
Highest Priced Tools $ 2800, e.g. Needle Guns, Scarifying Tools.
Highest cost of a fully configured "high end" vacuum power too] system is $32,000. Equipment with similar capabilities is available at one-fifth this cost. This includes self contained vacuum retrieval devices and disposal equipment.

FACT SHEET 5 - Containment with Use of Recyclable Media

AIR ABRASIVE BLASTING WITH RECOVERY OF BLAST MEDIA

OPERATING PARAMETERS

General Principles

- Abrasive blast cleaning in which the abrasive is recovered in a separate step following the surface preparation activity.

Air Pressure

- Between 85-100 PSIg at the nozzle measured by use of Hypodermic Pressure Gauge.

Attitude to Surface

- 90:1: 15° to plane. Some Equipment maintains perpendicular attitude to plane.

Abrasive Consumption

- Varies with abrasive. Typical consumption rates are 3 - 8 lb. per square foot for mineral abrasives.

Abrasive Mix

- Depends on required surface profile.

MateriaLs Required

- Steel Grit or Steel Shot or Reusable NEneral or Slag Abrasive.

Equipment Required

- For Blasting- Blast pot, compressor, blast hoses, blast nozzles, deadman switch, separate air supply for operator, anti-static grounding for bast equipment when working around volatile organic materials, fuels etc. For Recycling of Abrasive: Cyclone separator, filter apparatus to collect fines, abrasive debris. Vacuum hoses to collect used abrasive for recycling or some other collection device.

Reuse Capabilities

- Steel Grit Steel Shot - High *22 % loss* on each reuse of material. Approximately fifty recycles of material before complete replenishment of working mix..

Mineral / Slag Abrasive Ranges from a high of five to ten times reuse for selected mineral abrasives such as aluminum oxide or garnet to a low of 1.5 times reuse for boiler / copper slag materials.

Special Provisions

- Reuse of abrasive requires maintenance of a correct working mix. Particularly important for recycled steel abrasives.

Special uses

- Recycled abrasives are employed for two reasons, to reduce the volume of waste, or to capture and separate abrasives from hazardous (paint) materials.

Recommended Safety Equipment

- Deadman Switch on Abrasive Nozzle, Full Hood Respirator with Supplied Air, Steel Capped Safety boots. Other Safety equipment may be required for specific operations, for instance in removing hazardous materials in confined areas air flow must be maintained to prevent build up of air borne contaminants. High Efficiency Particulate Air filters may be needed to control emissions if the material being removed creates hazardous dusts

Expected Productivity

- For Blasting alone. Depends on coating being removed. Depends on degree of cleaning. Removal rates are between 200 - 2500 sq. ft. per hour peak productivity; the low range being SSPC-SP 5 cleaning, the high end SSPC-SP 7 cleaning. Over a typical shift removal rates may average 250 - 1500 sq. ft. per operator. These shift figures will also decline if the coating removal is to be conducted in a containment area. Under these conditions the set up time and take down time for the containment can consume a significant portion of the days activity thus achieved productivity will be that of two or three peak blasting hours spread over an eight hour period. Other time would be spent in cleaning up of the abrasive waste generated. This might result in productivity at a rate between 200 - 1300 sq. ft. per hour. These Productivity figures will decline if you take into account time required for clean up of abrasive, maintenance of recycling equipment, maintenance of working mix etc. Assume overall productivity in work session declines to 85 % of optimum, based on manufacturers claims published in "Surface Preparation the State of the Art', SSPC Conference Proceedings 1985.

FACT SHEET 6 - Open Air Abrasive Blasting

AIR ABRASIVE BLASTING UNCONFINED - WITH DISPOSABLE ABRASIVES

OPERATING PARAMETERS

General Pirinciples

- Abrasive particles are propelled toward the surface in a stream of high pressure air.

Air Pressure

- Typically between 85-100 PSIg at the nozzle measured by use of Hypodermic Pressure Gauge.

Attitude to Surface

- 90 ± 15° to plane.

Abrasive Consumption

- This is expressed in units of lbs. of abrasive per hour of blasting or lbs. of abrasive per square foot of cleaning. Actual consumption varies with abrasive specific gravity. Typical consumption rates are 3 - 8 lb. per square foot for total coating removal using mineral abrasives having a specific gravity in the range 2.5 to 4.0.

Abrasive Mix

- Depends on required surface profile.

Materials Required

- Mineral or Slag Abrasive. Conforming to MIL SPEC 22262 or SSPC Mineral and Slag Abrasive Specification, SSPC-AB 1.

Equipment Required

- Blast Pot, Compressor, Blast Hoses, Blast Nozzles, Deadman Switch, Separate air supply for operator, Anti-Static grounding for Blast Equipment when working around volatile organic materials, fuels etc.

Recommended Safety Equipment

- Deadman Switch on Abrasive Nozzle, Full Hood Respirator with Supplied Air, Steel Capped Safety boots. Other Safety equipment may be required for specific operations.

Expected Productivity

- Depends on coating being removed. Depends on degree of cleaning. Depends on pressure at nozzle. Depends on nozzle size. Removal rates are between 300 - 2500 sq. ft. per hour peak productivity for total coating removal (SSPC-SP 5 through SSPC-SP 7). Over a typical shift typical removal rates may average 300 - 2000 sq. ft. per hour per operator.

APPENDIX 3. Sources for Equipment Cost Data

Components	Source
Abrasive Blasting	
Air Compressor (13 00 CFM portable)	A. C
Blast Pot (pressure type)	A, B
Nozzles and hoses	A
Moisture and Air Control	
Air dryers and after coolers	A. C
Moisture and oil separators	A
Dust collector	A, B
Containment and Recycling	
Abrasive recycling unit	A, B
Grit cleaning Unit	A
Containment unit	H
Water Jetting	
HPWJ/UBPWJ machines(pumps)	A, F, G, H
HPWJ recycle unit (closed loop)	F, G
HPWJ hoses and lances	F, G
Vacuum and Power Tools	
Vacuum blast unit	A
Vacuum blast shrouds	A
Vacuum shrouded power tools	C
Media for power tools	C
Other	
Vacuum PD pump	A
High lift (Condor)	H

List of Sources
A = Carolina Equipment Company, Charlotte, NC
B = Clemco, Inc. Washington, MO
C = Ingersol Rand, Mocksville, NC
D = Unique Systems, Paterson, NJ
E = The Warehouse, Greensburg, PA
F = Flow International, Kent, WA
G = Waterblasters, Inc., Sewickley. PA
H = Infrastructure Technologies, Inc., Hamden, CT

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