ERDC/CERL TR-03-32

Construction Engineering
Research Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

# Technology Demonstration of Wet Abrasive Blasting for Removal of Lead- and Asbestos-Containing Paint

Timothy Race, Ashok Kumar, and L. D. Stephenson

December 2003

Approved for public release; distribution is unlimited.

ERDC/CERL TR-03-32

Construction Engineering Research Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

# Technology Demonstration of Wet Abrasive Blasting for Removal of Lead- and Asbestos-Containing Paint

Timothy Race, Ashok Kumar, and L. D. Stephenson

**Environmental Technology Demonstration**

ERDC/CERL TR-03-32
December 2003

# Technology Demonstration of Wet Abrasive Blasting for Removal of Lead- and Asbestos- Containing Paint

Timothy Race, Ashok Kumar, and L. D. Stephenson

*Construction Engineering Research Laboratory*
*PO Box 9005*
*Champaign, IL 61826-9005*

Final Report



Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit #CFM-B101

**ABSTRACT:** A group of 1940s-era concrete block buildings at Fort Carson, CO, must be demolished, but they are coated with lead-based paint containing asbestos filler that must both be disposed of as hazardous waste. In order to decrease waste disposal costs, an improved method was needed to remove both coatings while rendering the lead-containing debris non-leachable). This technology demonstration showed that wet blasting using an engineered abrasive can safely and effectively remove lead- and asbestos-containing paint from exterior concrete masonry unit walls, producing an asbestos-free substrate ready for conventional demolition or renovation. The combination of water injection into the blasting process and a ventilated containment structure produced zero visible emissions and complied with applicable asbestos and lead air quality standards. Use of the chemical stabilizing product Blastox® in the dry blast media eliminated the toxic lead characteristic from the paint removal waste. The estimated unit area cost (UAC) of the demonstrated technology was $7.87/sq ft, compared with an average contracted cost of $8.15/sq ft. Elimination of the hazardous waste stream provides the user with other benefits, including reductions in permitting, storage, and handling costs. The primary limitation of the technology is substrate damage caused by the aggressiveness of the abrasive.

# Contents

# List of Figures and Tables

## Figures



## Tables

# Conversion Factors

U.S. standard units of measure used in this report can be converted to SI units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4,046.873 | square meters |
| cubic feet | 0.02831685 | cubic meters |
| cubic in.es | 0.00001638706 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| degrees Fahrenheit | (5/9) x (°F – 32) | degrees Celsius |
| degrees Fahrenheit | (5/9) x (°F – 32) + 273.15. | kelvins |
| feet | 0.3048 | meters |
| gallons (U.S. liquid) | 0.003785412 | cubic meters |
| horsepower (550 ft-lb force per second) | 745.6999 | watts |
| in.es | 0.0254 | meters |
| kips per square foot | 47.88026 | kilopascals |
| kips per square in. | 6.894757 | megapascals |
| miles (U.S. statute) | 1.609347 | kilometers |
| lb (force) | 4.448222 | newtons |
| lb (force) per square in. | 0.006894757 | megapascals |
| lb (mass) | 0.4535924 | kilograms |
| square feet | 0.09290304 | square meters |
| square miles | 2,589,998 | square meters |
| tons (force) | 8,896.443 | newtons |
| tons (2,000 lb, mass) | 907.1847 | kilograms |
| yards | 0.9144 | meters |

# Preface

This study was conducted for Headquarters, Department of the Army under Program Element 063728A, "Environmental Technology Demonstration Project 002"; Work Unit number CF-M B101, "Cost Effective Technologies to Reduce, Characterize, Dispose, and Reuse Sources of Lead Hazards." The technical monitor was Bryan Nix, ACS (IM)-FDF.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Ashok Kumar. Part of this work was done by Corrosion Control Consultant and Laboratories (CCC&L) under contract No. DACA-42-02-P-0210. The technical editor was Gordon L. Cohen, Information Technology Laboratory. Martin J. Savoie is Chief, CEERD-CF-M, and L. Michael Golish is Chief, CEERD-CF. The Technical Director of the Installation Operations business area is Gary W. Schanche, CEERD-CV-T. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers.

At the time of preparation of this report, COL James R. Rowan, EN, was the Commander and Executive Director of ERDC, and Dr. James R. Houston was the Director.

# 1 Introduction

## 1.1 Background

Army policy and Federal regulation dictate that all friable and non-friable asbestos-containing materials (ACM) that will become friable during demolition, must be removed prior to building demolition. Surfacing ACMs such as paints and protective coatings can be removed effectively only by aggressive methods that pulverize the otherwise-intact ACM. Specific regulations, referenced below, govern worker and building occupant protection, release containment, and storage, transportation, and disposal of ACM waste.

Removal of lead-based paint (LBP) from exterior surfaces of commercial and industrial buildings is not required by regulation or Army policy. However, where removal of LBP is performed in conjunction with building renovation or ACM removal, certain regulations are invoked. These include ambient air quality standards for particulate matter and lead, identification and listing of hazardous waste, standards for generators and transporters of hazardous waste, emergency planning and notification, and safety and health for lead in the construction industry.

The demonstrated technology utilizes a combination of water, abrasive blasting media, and a chemical stabilizing agent. The water suppresses particulate emissions to reduce worker exposures as well as the risk of atmospheric release. The high-velocity blast medium removes the lead- and asbestos-containing paints. The chemical stabilizer, Blastox® (Hock et al. 1996; Hock et al. 1999), is mixed with the working abrasive and renders the waste nonhazardous for lead.

## 1.2 Objective

The purpose of the demonstration was to evaluate the cost and performance of wet abrasive blasting with a chemical stabilizer for removal of lead and asbestos containing paint. The primary performance objectives were elimination of the toxic lead characteristic and production of an asbestos-free substrate. A secondary performance objective was to eliminate visible emissions during coating removal.

## 1.3 Approach

An engineered abrasive containing Blastox was specified for the removal of LBP mixed with asbestos on concrete masonry units (CMU) in a building at Fort Carson, CO. The demonstration was conducted in October 2002. A cost/performance assessment was conducted to determine how effectively the abrasive removes LBP mixed with asbestos, and whether the resulting waste debris is nonhazardous.

## 1.4 Regulatory Drivers

Army policy (AR 420-70, *Facilities Engineering, Buildings and Structures*, Section II, "Asbestos Hazard Management, Disposition of Army Facilities with Asbestos-Containing Materials") states that prior to demolition, friable ACM or ACM that will become friable during demolition must be removed and disposed of in accordance with the National Emission Standards for Hazardous Air Pollution (40 CFR 61, Subpart M) and other applicable Federal, state, and local regulations. 40 CFR 61.145, *Standard for Demolition and Renovation*, requires ACM removal for demolition or renovation whenever the total surface ACM exceeds 160 sq ft. Additional requirements govern worker and building occupant protection, release containment, and storage, transportation, and disposal of ACM waste.

## 1.5 Mode of Technology Transfer

Technology transfer is being accomplished by: (1) a Technology Transfer Implementation Plan supervised by the U. S. Army Environmental Center (AEC); (2) dissemination of Public Works Technical Bulletin (PWTB) 420-70-2, "Installation Lead Hazard Management"; (3) participation in User Groups and Committees such as the Army Lead and Asbestos Hazard Management Team, Federal Lead-Based Paint Committee Meetings at EPA or HUD, and ASTM Committee E06.23 document entitled *Standard Practice for the Selection of Lead Hazard Reduction Methods for Identified Risks in Residential Housing or Child Occupied Facilities*; (4) websites maintained by the Assistant Chief of Staff for Installation Management (ACSIM) [http://www.hqda.army.mil/acsimweb/fd/policy/facengcur.htm], AEC [http://aec.army. mil/usaec/], and the U. S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) [http://www.cecer.army.mil], as well as the Hands-on-Skills Training (HOST) website [http://www.hqda.army.mil/acsimweb/fd/policy/host/index.htm]; (5) demonstration and validation of emerging technologies through Army technology demonstration funding (6.3) starting in fiscal year 2000 (FY00) and continuing through FY03, and cost/performance reports from those demonstrations, including a decision tree for selection of optimal LBP hazard management and removal techniques for Buildings.

# 2 Technology Description

## 2.1 Technology Development and Application

Water-injected abrasive blasting is a mature technology that has been commercially available for many years. Wet abrasive blasting uses an expendable abrasive media such as coal slag or silica sand to remove the paint. Amended water injected at the blast nozzle suppresses dust formation. The chemical stabilizer Blastox® has been shown to stabilize leachable lead in the waste stream, thus eliminating the hazardous characteristic for lead (Hock et al. 1996). The mixture is suitable for removing coatings from wood, steel, and cementitious surfaces. Blastox® has been commercially available since 1991 (TDJ Group product brochure, not dated). The intended use of the removal/stabilization technology in this demonstration is the abatement of asbestos- and/or lead-containing paints.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) performed laboratory and field evaluations of LBP removal using standard abrasive blast media combined with Blastox® (Hock et al. 1996). These tests confirmed the feasibility of removing and stabilizing LBP in a one-step process. Abrasive blasting successfully removed the paint and the chemical stabilizer immobilized the lead, allowing the waste to pass the U.S. Environmental Protection Agency (EPA) Toxic Characteristic Leaching Procedure (TCLP, EPA Method 1311). Several other agencies have evaluated the technology, including the Federal Highway Administration (FHWA 1995).

Blastox® reportedly works by several reactions, including encapsulating hydration reactions; addition and substitution reactions between heavy metal cations and calcium silicates; and pH modification. The pH modification is a result of hydration reactions, immobilizing the lead ions while allowing the remaining chemical reactions to occur. Lead compounds are chemically converted from soluble forms, such as lead oxide or lead hydroxide, to a stable lead silicate salt (Hock, Gustafson, and Drozdz 1998).

## 2.2 Process Description

All work performed in this demonstration was consistent with Class I asbestos abatement standards documented in two Unified Facilities Guide Specifications (UFGS). UFGS-13281A, *Lead Hazard Control Activities,* and UFGS-13280A, *Asbestos Abatement,* provide details on health, safety, and environmental requirements for lead and asbestos hazard control activities, respectively. The primary requirements are accident prevention planning, medical surveillance, respiratory protection, training, sampling and analysis, clearance testing, personal protective equipment, hygiene facilities, posted warnings and notices, work procedures, and hazardous waste handling.

The process consisted of five work phases: (1) mobilization, (2) paint removal, (3) cleanup, (4) clearance testing, and (5) demobilization.

Mobilization consisted of staging and erecting all project equipment, including the containment structure, critical barriers, decontamination area, air ventilation and filtration systems, blasting equipment, man-lift, waste storage area, and demarcation of the regulated area (Figure 1).

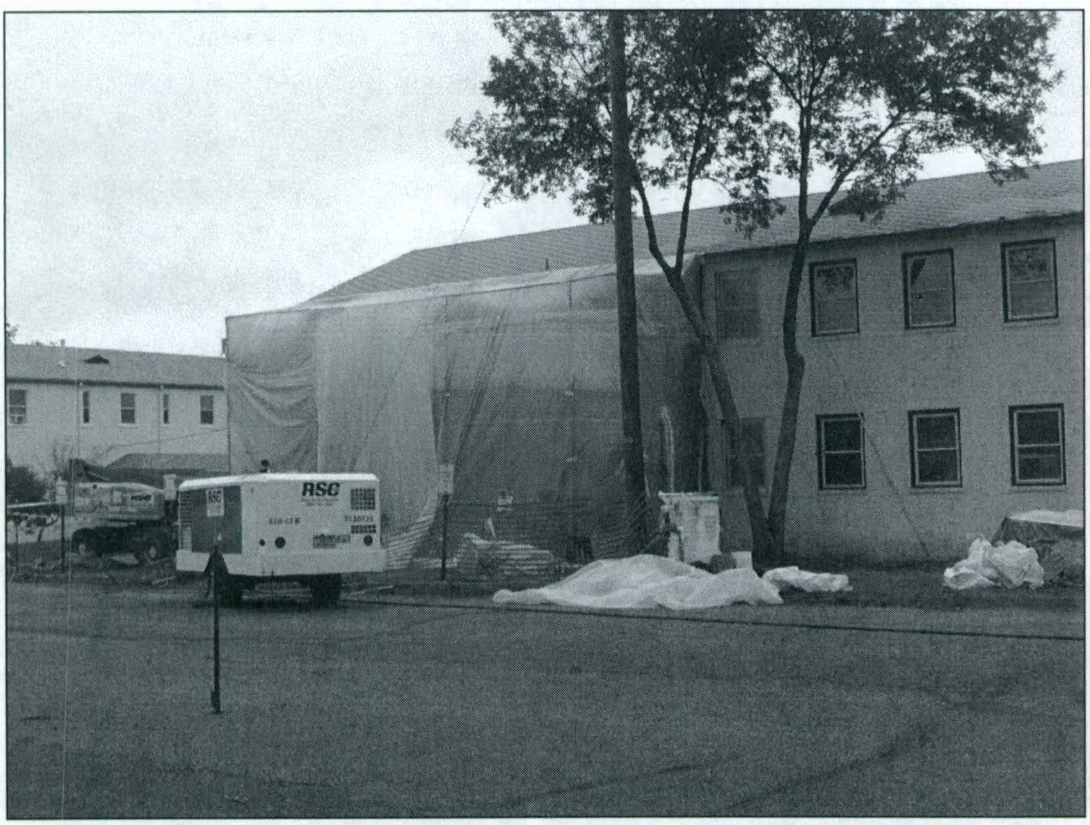


**Figure 1. Overview of paint removal operation.**

Critical barriers of 6 mil polyethylene (PE) sheeting were placed over all building openings including windows, doors, ventilation ducts, and other openings (Figure 2). A containment structure consisting of 6 mil reinforced PE sheeting affixed to a vertical pipe tube-frame structure (cover photograph) was erected. The tube-frame was attached to the CMU wall using screw fasteners. The containment floor was constructed of 1 in. plywood overlaid with two layers of 6 mil PE sheeting. The average containment structure measured 10 ft x 22 ft x 45 – 60 ft (depth, vertical height, horizontal length). The average coated surface area contained by the structure was 1000 sq ft. The decontamination area was a purpose-built plywood box enclosure connected to one end of the containment structure. Ventilation and high-efficiency particulate air (HEPA) air filtration was connected with two flexible 12 in. diameter tubes to the opposite end of the containment (Figure 3). Two ventilation fans rated at 2000 standard cubic feet per minute (scfm) each supplied a maximum ventilation capacity of 4000 scfm. Input air was forced-air using a 1900 scfm rated fan. The containment cross-sectional area was approximately 220 sq ft. The maximum calculated horizontal air velocity inside the containment was 18 feet per minute (fpm). The maximum tube transport velocity was 640 fpm. Air movement was confirmed using smoke tubes each time the containment was erected. Negative air pressure was confirmed using a manometer during operation (Figure 4). The containment and ventilation system utilized was approximately equivalent to SSPC-Guide 6, Class 1W (A1, B3, C1, D1, E2, F2, G1, H2, I1, J1) except that instrument verification of negative air pressure was required (H1) and minimum air velocity was not specified (I2).

**Figure 2. Critical barrier of 6-mil polyethylene sheeting placed over window.**

Figure 3. Ventilation units and ducts attached to end of containment.

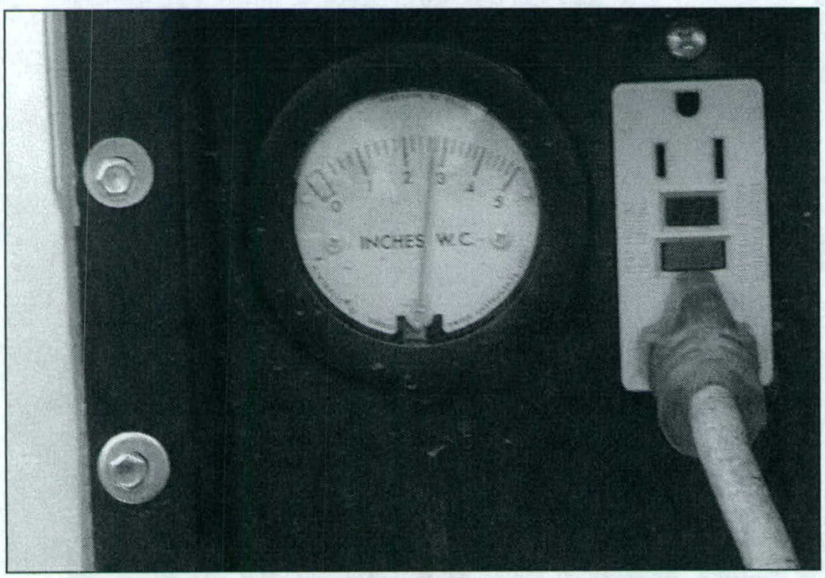


Figure 4. Negative pressure inside of containment as indicated by manometer.

Blasting equipment consisted of a 1500 lb blast pot, 600 scfm air compressor, hoses, and blast nozzle equipped with a water ring. The water ring was supplied on demand with potable water amended using an in-line surfactant mixer.

A 60 ft boom-type man lift was positioned outside the containment with the boom inserted through the containment wall. The regulated area was demarcated using signs and tape, and the waste storage area was sited close to the containment structure (Figure 5).

Prior to paint removal, amended water was applied to the painted surfaces until adequately wet. Paint removal was by pressurized air abrasive blasting using an unspecified blast nozzle and air pressure. Blast media was #10 silica sand. Water amended with a non-ionic surfactant at 0.5 to 1.0% by volume was introduced using a water ring with an estimated flow rate of 1 to 2 gallons per minute (gpm). Blast media consumption averaged about 4.0 lb/sq ft of paint removed.

Personal air monitoring (PAM) was conducted to assess worker lead and asbestos exposures for the blaster and blast pot tender (Figure 6). Periodic air monitoring for ambient lead and asbestos concentrations was also performed to assess containment and ventilation efficacy.

**Figure 5. Forty cubic yard roll-off waste container.**

Figure 6. Low-volume air pump for PAM sampling.

Cleaning and bulk debris removal were performed after paint removal. Bulk cleanup of wet debris was done with shovels. After bulk debris removal, a final cleaning was performed using HEPA vacuum and wet cleaning of all exposed surfaces within the containment. After final cleaning, a visual inspection was performed. Additional cleaning was performed as needed. Prior to removal of PE sheeting, and after cleanup of gross contamination and final visual inspection, a post-removal "lockdown" encapsulant was applied to all interior surfaces of the containment using an airless spray unit.

After cleanup and lockdown, an independent certified industrial hygienist performed visual and instrumental inspections. Surfaces were considered asbestos-free when no areas of residual coating greater than the size a quarter dollar were present (Figure 7). Secondary remediation (i.e., touchup paint removal) was accomplished using a vacuum-assisted needle gun. Instrumental methods were used to determine that the air within the containment met the air clearance criteria specified in UFGS 13280A, para 3.9.7.

Containment was disassembled, and the bulk and low-density debris were placed in the specified disposal containers and packaged and stored as required (Figure 8).

Bulk waste was sampled and tested for the toxic lead characteristic. Aggregated waste was hauled to a Toxic Substances Control Act (TSCA) landfill for disposal.

**Figure 7. Rough substrate free of ACM.**

**Figure 8. Low-density waste in roll-off container.**

## 2.3 Previous Testing of the Technology

As discussed previously, research by ERDC/CERL has demonstrated the feasibility of removing and stabilizing LBP with Blastox® in a one-step process. Dry abrasive blasting was used to remove LBP, and the chemical stabilizer immobilized the lead, creating a waste characterized as nonhazardous according to the TCLP. Laboratory analyses by ERDC/CERL showed Blastox® to be a calcium silicate-based material with stabilization mechanisms similar to those of portland cement (Hock et al. 1996). The analyses showed that chemical substitution reactions and physical encapsulation of the waste provide a containment matrix with excellent long-term stability. This chemical stabilizing abrasive blasting technology is reported to have performed well in field demonstrations on both wood and steel substrates. Because the resulting waste is verifiably nonhazardous, the cost of waste disposal is dramatically reduced. Consequently, the use of Blastox® was estimated to provide cost savings of $0.12 to $0.44/sq ft of abated surface for wood substrates, and $0.93 to $3.06/sq ft for steel substrates.

The manufacturer of Blastox®, the TDJ Group, Inc.*, evaluated disposal costs for a large number of abrasive blast cleaning jobs using mineral abrasive with and without Blastox®. TDJ's data show an average cost for purchase and disposal as a nonhazardous waste of $188 per ton of abrasive. Mineral abrasive without Blastox® was used and disposed of as hazardous waste at an average cost of $296 per ton of abrasive. The average disposal cost savings per ton of abrasive consumed is $108.

## 2.4 Advantages and Limitations of the Technology

In addition to the disposal cost benefit discussed above, wet abrasive blasting has a relatively high production rate. Also, the addition of water to the process suppresses dust formation, which reduces worker and environmental exposures to hazardous lead and asbestos. The process has several limitations. Wet abrasive blasting is quite aggressive and will rapidly degrade cementitious surfaces if blast pressures and dwell times are not closely monitored. On concrete masonry unit (CMU) walls, grout is more susceptible to damage than the block face, so preferential erosion of the grout lines will occur. For renovation projects this may mean that the block will require re-grouting. Adjacent surfaces such as wood window frames

* TDJ Group, Inc., Cary, IL, 60013.

may also be inadvertently damaged (Figure 9). Wet abrasive blasting also creates a sludge that can be difficult to clean up (Figure 10).

**Figure 9. Incidental damage to wood window frame caused by wet abrasive blasting.**

Figure 10. Water and sludge on containment structure floor.

## 2.5 Competing Technologies

Competing technologies for paint removal from concrete discussed SSPC-SP13, *Surface Preparation of Concrete* include dry abrasive blasting with recyclable abrasive, wet abrasive blasting, high-pressure water cleaning, water-jetting with or without abrasive, impact tools, power tools, flame blasting, and chemical stripping.

Open dry abrasive blasting cannot be used for Class 1 asbestos removal because for wetting of the ACM is required. Wet abrasive blasting (as tested herein) and slurry blasting greatly reduce dusting and have high production rates.

Sponge blasting can be performed using a dust suppressant or water. Sponge media properties can be adjusted to be less aggressive than other hard media in order to reduce substrate damage. Sponge media can also be cleaned and recycled to reduce waste. However, sponge blasting requires purpose-built equipment that may be less available and more costly than conventional blasting equipment. High-pressure water cleaning eliminates dust but has lower production rates than blasting methods. Water filtering and re-use can reduce overall waste production. Water-jetting also reduces dust but it is very aggressive and can produce a very coarse surface profile on concrete.

Impact tools create dust and a coarse surface profile, and they may fracture concrete. Dust can be reduced by collecting at the point of generation using a vacuum-assisted tool with HEPA filtration. Power tools also create dust, but they also can be outfitted as vacuum-assisted units. Both power and impact tools are relatively slow. Rotary power tools may not be capable of removing all of the coating embedded in a rough surface such as concrete block.

Flame blasting is a poor choice for removing LBP because the high temperature can volatize lead compounds to create worker safety and environmental hazards. Flame blasting may also damage the concrete substrate.

Chemical stripping is a poor choice for porous or rough substrates such as concrete block because complete coating removal is difficult. Another problem is that chemical stripper wastes often exhibit the hazardous characteristic for corrosivity or are flammable.

Of the available paint removal technologies, the most suitable for lead- and asbestos-containing coatings on CMU walls are water-injected abrasive blasting and slurry blasting. Either method may be further enhanced by using a chemical stabilizer such as Blastox® to eliminate the hazardous lead characteristic. Sponge blasting also offers some attractive benefits. High-pressure water cleaning used in conjunction with a topical chemical stabilizer such as Enviro-Prep or PreTox2000 may also be competitive. Topical stabilizers are spray-applied coatings that contain a chemical stabilizer. The stabilizer in the topical coating mixes with the hazardous paint waste and blast media residue to produce a nonhazardous waste.

# 3 Demonstration Design

## 3.1 Performance Objectives

The primary performance objectives of this demonstration are listed in Table 1.

**Table 1. Performance objectives.**

| Performance Objective Type | Primary Performance Criterion | Expected Performance (Metric) | Performance Objective Met? |
|---|---|---|---|
| Quantitative | Elimination of hazardous lead characteristic | < 5 ppm Pb | Yes |
| Quantitative | Elimination of surfacing ACM | Residual paint less than 0.25 in. diameter | Yes |

## 3.2 Selection of Test Site

The old hospital complex at Fort Carson, CO, was selected as the test site because the structures are coated with both LBP and ACM on their exteriors. Some structures are earmarked for demolition and others are to be renovated. Before the demolition/renovation project began, the complex consisted of 31 buildings having a total 636,000 sq ft of exterior wall space. The buildings are built primarily of CMU primed with asbestos-containing block filler topcoated with LBP. Typical coating thicknesses are 50 to 75 mils.

## 3.3 Sampling and Monitoring Procedures

Worker safety is a primary consideration in the abatement of any hazardous material, including LBP and ACM. Figure 11 shows the whole-body protective gear used by the workers. These protective suits conform to the requirements of UFGS 13280A, para 1.15.2. Worker exposure to respirable lead and asbestos were evaluated periodically. Clearance testing for asbestos in air was performed each time the containment structure was ready for dismantling. Environmental exposure was assessed by monitoring visible emissions as well as by collecting area samples using high-velocity air sampling methods. The specific performance objectives for this demonstration were elimination of surfacing ACM and the hazardous lead characteristic. Residual ACM was evaluated by visual inspection. Waste samples were evaluated for leachable lead using the TCLP.

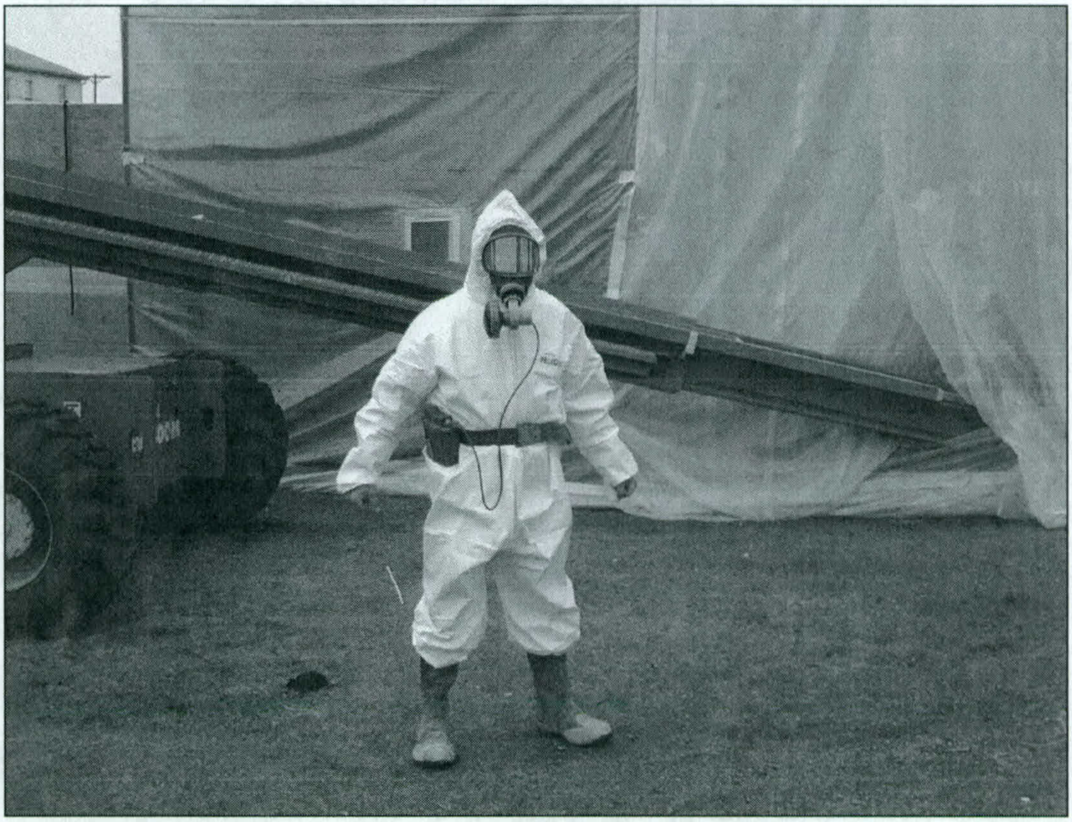

Figure 11. Personal protective equipment worn by abrasive blaster.

## 3.4 Analytical Procedures

Solid wastes were prepared for characterization in accordance with EPA 1311 (*TCLP for Metals*) and analyzed in accordance with EPA 6010B (*ICP-AES Method for Determination of Metals*). Personal and area samples were analyzed for lead in accordance with National Institute for Occupational Safety and Health (NIOSH) Method 7300, *Air Sampling for Metals* (see results in Section 4.2). Results of testing are time-weighted averages for 8-hour exposures.

# 4 Performance Assessment

## 4.1 Performance Criteria

As stated previously, the primary objectives of this demonstration were elimination of surfacing ACM and the hazardous lead characteristic.

The presence of residual ACM was evaluated by visual inspection. In some cases areas larger than 0.25 in. in diameter were identified and marked by the inspector. Marked areas were re-cleaned using a vacuum-assisted impact tool (needle gun). This secondary remediation touchup process (see Section 2.2) does not represent a deviation from the test's performance goals and objectives because it was included in the process by design.

Waste samples were collected and prepared for characterization in accordance with EPA 1311 (*TCLP for Metals*) and analyzed in accordance with EPA 6010B (*ICP-AES Method for Determination of Metals*). Abrasive blasting debris was sampled and evaluated nine times to ensure that waste from throughout the entire 17,600 sq ft building was represented. All of the samples evaluated tested below 5 ppm leachable lead. The average leachable lead content was 1.17 ppm. All abrasive blasting debris was therefore considered nonhazardous and was suitable for disposal at the State of Colorado-approved asbestos disposal site, the Denver Arapahoe Disposal Site (DADS).

## 4.2 Data Assessment

The performance goals for this technology evaluation were met. The test results substantiated the manufacturer's claims for the efficacy of the blast media waste stabilizer.

The addition of surfactant-amended water to the abrasive media reduced dust production enough to eliminate visible dust emissions inside the containment structure, bringing air monitoring results into compliance with the requirements of UFGS 13280A and 13281A. The spray application of a lockdown encapsulant ensured that tests for residual airborne asbestos contamination were acceptable.

Abrasive blasting successfully removed all visible ACM at an acceptable rate. As noted above, occasional spots deviating from the acceptance criteria were successfully remediated using a vacuum-assisted needle gun.

Workers were adequately protected against airborne lead. Personal air monitoring (PAM) results within the containment structure averaged 23 $\mu g$ $Pb/m^3$, well below both the permissible exposure limit (50 $\mu g$ $Pb/m^3$) and the action level (30 $\mu g$ $Pb/m^3$). Powered air purifying respirators (PAPR) were used with an assigned protection factor (APF) of 50 and a maximum use concentration (MUC) of 2500 $\mu g$ $Pb/m^3$.

## 4.3 Technology Comparison

In addition to water injected abrasive blasting, slurry blasting is another suitable paint removal technology for lead and asbestos containing coatings on CMU substrates. Slurry blasting may be further enhanced by using a chemical stabilizer such as Blastox® to eliminate the hazardous lead characteristic. Sponge media also offers attractive benefits including the ability to reduce waste by recycling the media and to reduce dust production through the addition of water. High-pressure water cleaning used in conjunction with a topical chemical stabilizer such as Enviro-Prep or Pretox2000™ may also be competitive in some cases. Enviro-Prep offers benefits similar to Blastox®. However, an additional step is required to apply the chemical stabilizer to the substrate before removing the LBP. Cost studies have not been conducted for these competing processes in terms of the operational requirements applicable to Fort Carson. However, the costs and benefits of these technologies should be similar to wet abrasive blasting with mineral sand and Blastox®.

# 5 Cost Assessment

## 5.1 Cost Reporting

Unit area costs were calculated based on the various costs for the demonstration. Cost data are reported in Table 2.

**Table 2. Estimated cost per 1000 square foot contained area.**

| Work Phase | Cost Item | Quantity | Unit Cost | Item Cost | Direct Labor Costs | Other Direct Costs |
|---|---|---|---|---|---|---|
| *Containment Erection* | Labor, crew | 40 hours | $17.73/h | $709.20 | | |
| | Labor, supervisor | 1 hour | $30.00/h | 30.00 | | |
| | Man lift rental | 2.5 days | $66.50/day | 166.25 | | |
| | PE sheeting | 1000 sq ft | $0.0175/sq ft | 17.50 | | |
| | Reinforced PE sheeting | 2040 sq ft | $0.0495/sq ft | 100.98 | | |
| | Duct tape | 1 roll | $8.56/ea | 8.56 | | |
| | Diesel Fuel | 10 gallons | $1.50/gal | 15.00 | $739.20 | $308.29 |
| *Paint Removal and Cleanup* | Labor, pot tender and blaster | 20 hours | $17.73/h | 354.60 | | |
| | Labor, supervisor | 2 hour | $30.00/h | 60.00 | | |
| | Abrasive, #10 silica sand | 3000 lb | $0.085/lb | 255.00 | | |
| | Blastox | 1000 lb | $0.38/lb | 380.00 | | |
| | Surfactant | 5 gallons | $3.60/gal | 18.00 | | |
| | Diesel fuel | 75 gallons | $1.50/gal | 112.50 | | |
| | Man lift rental | 1.5 days | $66.50/day | 99.75 | | |
| | Compressor rental | 6 days | $57.00/day | 342.00 | | |
| | Respirator filters, PAPR | 3 | $8.50/ea | 25.50 | | |
| | Respirator filters, half-face | 2 | $3.00/ea | 6.00 | | |
| | Pb cassettes | 1 | $0.80/ea | 0.80 | | |
| | Asbestos cassettes | 1 | $0.66/ea | 0.66 | | |
| | PAM Pb test | 1 | $10.00/ea | 10.00 | | |
| | PAM asbestos test | 1 | $15.00/ea | 15.00 | | |
| | PPE, Tyvek coverall | 4 | $3.60/ea | 14.40 | | |
| | PPE, cotton skivvies | 4 | $1.04/ea | 4.16 | | |

| Work Phase | Cost Item | Quantity | Unit Cost | Item Cost | Direct Labor Costs | Other Direct Costs |
|---|---|---|---|---|---|---|
| | PPE, shorts | 4 | $0.84/ea | 3.36 | | |
| | PPE, gloves | 2 pairs | $1.33/pr | 2.66 | | |
| | Tear-off lens guards | 1 package | $30.00/pkg | 30.00 | | |
| | Area air sample and test | 1 | $57.00/ea | 57.00 | | |
| | Ventilation, prefilters | 1 case | $30.00/cs | 30.00 | | |
| | Ventilation, secondary filters | ½ case | $39.00/cs | 19.50 | 414.60 | 1426.29 |
| *Lockdown Encapsulant Application* | Labor, crew | 4 hours | $17.73/h | 70.92 | | |
| | Labor, supervisor | ½ hour | $30.00/h | 15.00 | | |
| | Encapsulant | 5 gallons | $19.60/gal | 98.00 | | |
| | Man lift rental | 1 day | $66.50/day | 66.50 | | |
| | Compressor rental | 1 day | $57.00/day | 57.00 | | |
| | Diesel fuel | 15 gallons | $1.50/gal | 22.50 | 85.92 | 244.00 |
| *Clearance Testing* | Certified industrial hygienist | 1 site visit | $155.00/ea | 155.00 | 0.00 | 155.00 |
| *Containment Dismantling* | Labor, crew | 16 hours | $17.73/h | 283.68 | | |
| | Labor, supervisor | ½ hour | $30.00/h | 15.00 | | |
| | Man lift rental | 2 day | $66.50/day | 133.00 | 298.68 | 133.00 |
| *Waste Disposal* | Disposal, low density | 7.5 cy | $22.00/cy | 165.00 | | |
| | Disposal, high density | 1.5 cy | $22.00/cy | 33.00 | | |
| | Transportation | ½ roll off | $375.00/ea | 187.50 | 0.00 | 385.50 |

**Table 2 (Continued): Estimated cost per 1000 square foot contained area.**

| Cost Category | | | | |
|---|---|---|---|---|
| *Total Direct Labor Cost* | $1538.40 | | | |
| *Total Other Direct Costs* | 2652.08 | | | |
| *Overhead on Direct Labor @ 70.0%* | 1076.60 | | | |
| *Total Direct Costs and Overhead* | | $5267.08 | | |
| *General and Administrative @ 30.0%* | | 1580.12 | | |
| *Total Direct and Indirect Costs* | | | $6847.20 | |
| *Profit @ 15.0%* | | | 1027.08 | |
| **Total Cost** | | | | $7874.28 per 1000 sq ft |
| ***Total Unit Area Cost (UAC)*** | | | | $7.87/sq ft |

## 5.2 Cost Analysis

Cost assumptions include prevailing wages, including benefits, for common laborers for El Paso County, CO (Davis-Bacon Act wage determinations effective October 2002). The supervisory labor cost is estimated. Material costs and utilization are those reported by the contractor. Overhead rate estimates are based on ranges recommended for development of an independent government cost estimate (IGCE) in the Defense Information Systems Agency (DISA) *Acquisition Deskbook.** DISA recommends an overhead rate on unburdened labor between 30% and 70% for work performed at a government site. General and Administrative (G&A) rates range from 5% to 30%. The profit estimate should reflect a percentage typical for the industry. The high end of the overhead and G&A ranges were used for the reported cost.

Major cost components include labor, equipment rental, blast media, diesel fuel, lockdown encapsulant, and waste disposal. The paint removal process itself is efficient, so significant labor cost savings in this area are unlikely. However, setup and teardown of the containment are labor-intensive, and labor cost savings in this area may be possible through improved engineering and design of the containment. Diesel fuel and encapsulant consumption reflect actual usage, so the potential cost savings for these and other consumables are negligible. The waste disposal cost reflects the fact the there is only one asbestos waste disposal site in the state of Colorado. However, most of the waste volume is low-density material – primarily PE sheeting from the containment. Because the waste disposal cost is based on volume rather than weight, some cost savings may be possible if the debris is compacted.

The work performed by the contractor at Fort Carson is production-scale work, so no extrapolation is required to calculate actual costs. The work is being conducted on an ongoing basis. Table 3 expresses the actual cost for a 1000 square foot contained surface area. Costs are based on the contracted cost by line item. The estimated cost is about 3% lower than the actual cost to the government. Actual costs may vary depending on the size of area contained. An 800 square foot area would result

---

* After this research was completed, the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD [AL&T]) authorized transitioning of the *Acquisition Deskbook* from a web-based server into an online library called the "Knowledge Sharing System." The so-called "Legacy Deskbook" referenced here is now hosted at http://legacydeskbook.dau.mil/. The reference list at the end of this report includes the web address for the *Acquisition Deskbook* at the time this portion of the research was conducted.

in a cost of about $8.60/sq ft compared to $8.15/sq ft for a 1000 square foot area. A 1200 square foot area would cost somewhat less at about $7.85/sq ft. The estimated and actual costs to the Government are quite close.

**Table 3. Contracted cost per 1000 square foot contained area.**

| Cost Item | Contract Cost |
|---|---|
| Containment Setup | $775.00 |
| Area Air Sampling | 57.50 |
| Personal Air Sampling and Analysis for Asbestos | 15.00 |
| Remove Asbestos Containing Paint – $5.00/sq ft to 10 ft height (450 sq ft) | 2250.00 |
| Remove Asbestos Containing Paint – $5.00/sq ft above 10 ft height (550 sq ft) | 3850.00 |
| Lockdown Encapsulation –$0.15/sq ft (2050 sq ft) | 307.50 |
| Final Air Monitoring | 155.00 |
| Waste Disposal – 40 yard roll-off for ACM at $1490.00 each (1/2 per 1000 sq ft) | 745.00 |
| Total Cost per 1000 sq ft Area | $8155.00 |
| Cost per Square Foot | $8.15 |

## 5.3 Cost Comparison

This demonstration project utilized a chemical stabilizer to eliminate the hazardous lead characteristic from the blast waste. Had the stabilizer not been used, waste disposal costs would have been higher and consumable blast media costs would have been lower. The direct cost of the chemical stabilizer was $0.38/sq ft. Had the stabilizer not been used, the consumption rate for silica sand would have been about $0.085/sq ft higher. The net added direct cost of using the stabilizer then was $0.295/sq ft. The blasting debris would have been more expensive to landfill had the chemical stabilizer not been used. It was assumed that the low-density debris (i.e., the PE sheeting) could be segregated from the hazardous blast debris because any dust attached to the sheeting would have been stabilized during blasting and, thus, would not exhibit the hazardous lead characteristic. The average U.S. disposal cost for hazardous and nonhazardous blasting debris is $296/ton and $188/ton, respectively, the net cost difference being $108/ton of blast debris. About 4000 lb of abrasive were used to clean 1000 sq ft. Allowing for a 10% weight gain from water and removed coating increases the waste generated to 4400 lb or 2.2 tons. Applying the cost-reduction factor of $108/ton of blasting debris, the direct cost savings would be about $238 per 1000 sq ft, or $0.238/sq ft. Using these costs it would appear that using the chemical stabilizer is not cost-effective. However, the disposal cost for high-density debris (i.e., blast media waste) using the DADS facility amounted to only about $33 per 1000 sq ft.* Comparing this cost to a projected hazardous waste cost of $651.20 (2.2 tons at $296/ton) shows a savings of $618.20 per 1000 sq ft or $0.618/sq ft. Subtracting the direct cost of the stabilizer ($0.618/sq ft - $0.295/sq ft) shows a savings of $0.323/sq ft. Escalating this cost to reflect the contractor's indirect costs and profit indicates a potential net savings of $0.483/sq ft. Other cost savings can also be attributed to elimination of the hazardous waste characteristic, including reduced permitting, storage, and transportation costs. It should also be recognized that wastes containing both lead and ACM must be disposed of according to the regulations pertaining to the more hazardous component (in this case lead, because lead is leachable while asbestos is not).

An alternative to chemical stabilizers that are added to the abrasive are stabilizer products that are applied as coatings over the substrate prior to removing the LBP. The application rate must be monitored to assure that an adequate amount of stabilizer is used per unit area in order to eliminate the lead hazard. Two examples of such typical stabilizers are PreTox2000 and Enviro-Prep. The average cost of these products is about $25/gallon. The average spreading rate needed to eliminate the lead hazard, as claimed by the product manufacturers, is 200 sq ft/gal. Therefore, the unit area cost for the material is $0.125/sq ft. If the product is applied at 500 sq ft/hour, the direct labor cost of application would be $0.035/sq ft. The total direct cost of using the topical stabilizer would be about $0.16/sq ft. Escalating to include the contractor's indirect costs and profit, the topical stabilizer net cost is approximately $0.276/sq ft. The escalated cost of hazardous waste disposal savings is $0.924/sq ft ($0.618/sq ft x 1.30 G&A x 1.15 profit). The net potential savings using a topical stabilizer is $0.648/sq ft compared to the blast additive stabilizer at $0.483/sq ft. It should be noted that in some cases the topical stabilizer needs to be applied at about twice the thickness specified above (i.e., 100 sq ft/gal) in order to eliminate the lead hazard. In such cases, the net savings for the topical stabilizer would be only $0.461/sq ft.

---

* This conspicuously low cost is location-specific and probably due to the fact that the DADS tip fee is based on volume rather than weight. This fee structure is more economical for high-density wastes such as spent blast media than for low-density wastes.

# 6 Summary and Conclusion

## 6.1 Implementation Costs

Major cost elements of wet blasting with an added lead stabilizer (in this case, Blastox) include containment structure erection, paint removal and cleanup, lockdown encapsulant application, environmental and health monitoring, containment dismantling, and waste disposal. Because setup and teardown of the containment are labor-intensive, some labor cost savings in this area may be possible through improved engineering and design of the containment. The paint removal process itself is efficient, so significant labor cost savings in this area are unlikely. Most of the waste volume is low-density material — primarily the PE sheeting used on the containment structure. Because the waste cost is based on volume rather than weight, some cost savings may be possible if the debris is compacted.

## 6.2 Performance Observations

The two primary performance goals of the project were met. The lead characteristic was eliminated through the use of a chemical stabilizer added to the blast media. Surfacing ACM was safely and efficiently removed in accordance with State of Colorado criteria to produce an ACM-free surface. Workers were not exposed to lead above the permissible exposure limit. Area monitoring and air clearance testing were acceptable. After completion of the wet blasting process, demonstration site buildings were tested and confirmed to be free of ACM and LBP, and they could then be demolished or renovated in accordance with the installation's facility plans.

The paint removal process produces a very rough substrate. It damages the mortar and in some cases adjacent wood substrates. Although this incidental damage is not an issue for buildings slated for demolition, it is an important consideration for buildings which are to be renovated. Concrete resurfacing is probably not required for renovation, but mortar repair will be required.

## 6.3 Scale-up

There are no scale-up issues as the work being performed by the paint removal contractor at Fort Carson is already a production-scale operation.

## 6.4 Regulatory Compliance and Acceptance

Army policy (AR 420-70, *Facilities Engineering, Buildings and Structures*, Section II, "Asbestos Hazard Management, Disposition of Army Facilities with Asbestos-Containing Materials") states that prior to demolition, friable ACM or ACM that will become friable during demolition, will be removed and disposed of in accordance with the *National Emission Standards for Hazardous Air Pollution* (40 CFR 61, Subpart M) and other applicable Federal, state, and local regulations. 40 CFR 61.145, *Standard for Demolition and Renovation*, requires ACM removal for demolition or renovation whenever the total surface ACM exceeds 160 sq ft. Wet abrasive blasting was used to meet the requirements of these regulations. Additional requirements govern worker and building occupant protection, release containment, and storage, transportation, and disposal of ACM waste. These requirements were met by utilizing procedures consistent with UFGS 13280A, *Asbestos Abatement*.

For ACM, another applicable mandate was Colorado Air Quality Control Commission Regulation No. 8, Part B, "Emission Standards for Asbestos." This standard allows no areas of surfacing ACM "larger than a pencil eraser head." Where so indicated by the presence of residual surface ACM, regulatory compliance was ensured through touchup using a vacuum-assisted needle gun.

# References

Army Regulation [AR] 420-70, *Facilities Engineering, Buildings and Structures* (Headquarters, Department of the Army [HQDA], Washington, DC, 10 Oct 1997).

*Acquisition Deskbook – Independent Government Cost Estimates* (Defense Information Systems Agency, 1998), currently available online only at http://legacydeskbook.dau.mil/; previously hosted at http://disa.dtic.mil/D4/igce98.html.

Blastox® Technical Data Sheet. TDJ Group, Cary, IL (not dated). http://www.blastox.com/tech_data.htm

Boy, J., and A. Kumar, "Lead -Based Paint Hazard Mitigation" in *The Encyclopedia of Environmental Analysis and Remediation*, Robert A. Meyers, Ed. (John Wiley and Sons Inc., 1998), pp 2501- 2516.

Colorado Air Quality Control Commission, Regulation No. 8, Part B, "Emission Standards for Asbestos" (Colorado Department of Public Health and Environment, 30 March 2003).

Davis-Bacon Wage Determinations, U.S. Government Printing Office (on GPO Access) http://www.access.gpo.gov/davisbacon/

FHWA-RD-94-100, *Lead-Containing Paint Removal, Containment, and Disposal* (Federal Highway Administration, February 1995).

Hock, Vincent F., Curt M. Gustafson, and Susan A. Drozdz, "Modified Abrasive Blast/Chemical Stabilizer Admixtures for Removal of Lead-Based Paint" *Proceedings of the 1998 Heartland Technology Transfer Conference*, Indianapolis, IN, June 1998.

Hock, Vincent F., Susan A. Drozdz, Malcolm E. McLeod, and Charles W. Racine, *Users Guide and Specifications for Using Blastox to Remove and Stabilize Lead-Based Paint*, Technical Report [TR] 99/97/ADA376176 (U.S. Army Construction Engineering Research Laboratory [USACERL], December 1999).

Hock, Vincent F, Susan A. Drozdz, Curt M. Gustafson, and Donald M. Cropek, *Demonstration of Lead-Based Paint Removal and Chemical Stabilization Using Blastox®*, Technical Report [TR] 96/20/ADA319807 (U.S. Army, Construction Engineering Research Laboratory [USACERL], October 1996).

NIOSH Method 7300, *Air Sampling for Metals* (National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, 7 October 1994).

Oklahoma State Regents for Higher Education, OSRHE Safety Newsletter, *Management and Disposal of Lead-Based Paint Debris,* University of Oklahoma, Oklahoma City. April 2000. http://www.okhighered.org/trainingcenter/osrhe/management_and_disposal_of_lead_paint.htm

SSPC-Guide 6, *Guide for Containing Debris Generated During Paint Removal Operations.*

SSPC-SP13, *Surface Preparation of Concrete.*

Unified Facilities Guide Specifications, Section 13280A, *Asbestos Abatement* (November 2001).

Unified Facilities Guide Specifications, Section 13281A, *Lead Hazard Control Activities* (March 2002).

# Points of Contact

| Name | Organization | Phone/Fax/E-mail | Role in Project |
|---|---|---|---|
| Dr. Ashok Kumar | ERDC/CERL<br>P. O. Box 9005<br>Champaign, IL 61826-9005 | Tel: 217-373-7235<br>Fax: 217-373-7222<br>E-mail: a-kumar@cecer.army.mil | Principal Investigator |
| Dr. L. D. Stephenson | ERDC/CERL<br>P. O. Box 9005<br>Champaign, IL 61826-9005 | Tel: 217-373-6758<br>Fax: 217-373-7222<br>E-mail: l-stephenson@cecer.army.mil | Research COTR* |
| Tim Race | Corrosion Control Consultants and Labs<br>135 Addison Ave., Suite 108<br>Elmhurst, IL 60126 | Tel: 630-834-3811<br>Fax: 630-834-3812<br>E-mail: trace@ccclabs.com | Principal Consultant |
| James Gray | Directorate of Environmental Compliance and Management (DECAM)<br>HQ, 7th ID and Fort Carson<br>801 Tevis Street Bldg 302<br>Fort Carson, CO 809132-4000 | Tel: 719-526-3127<br>Fax: 719-526-1705<br>e-mail: grayj@Carson-exch1.army.mil | Project COTR |
| Rob Ford | E2M<br>348 Specker Avenue<br>D.P.W. Contractors Yard<br>Fort Carson, CO 80913 | e-mail:rford@e2m.net<br>Tel: 719-540-3762<br>FAX: 719-540-6553 | Designated Competent Person |
| Richard Gallegos | E2M<br>348 Specker Avenue<br>D.P.W. Contractors Yard<br>Fort Carson, CO 80913 | e-mail:rgallegos@e2m.net<br>Tel: 719-540-6550<br>FAX: 719-540-6553 | Project Supervisor |

* COTR: Contracting Officer Technical Representative.

# Acronyms Used

| | |
|---|---|
| ACM | asbestos-containing material |
| AL | action level |
| APF | Assigned Protection Factor |
| AR | Army Regulation |
| ASTM | formerly American Society for Testing and Materials, now simply ASTM International |
| CFR | Code of Federal Regulations |
| CMU | concrete masonry unit |
| DADS | Denver Arapahoe Disposal Site |
| DISA | Defense Information Systems Agency |
| EPA | U.S. Environmental Protection Agency |
| FHWA | Federal Highway Administration |
| FPM | feet per minute |
| HEPA | high efficiency particulate air |
| ICP-AES | inductively coupled plasma – atomic emission spectroscopy |
| LBP | lead-based paint |
| MUC | maximum use concentration |
| PAM | personal air monitor |
| PAPR | powered air purifying respirator |
| PE | polyethylene |
| PEL | permissible exposure limit |
| PPM | parts per million |
| SCFM | standard cubic feet per minute |
| SSPC | The Society for Protective Coatings (formerly Steel Structures Painting Council) |

| | |
|---|---|
| TCLP | Toxic Characteristic Leaching Procedure |
| TSCA | Toxic Substances Control Act |
| UAC | unit area cost |
| UFGS | Unified Facilities Guide Specification |

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE (DD-MM-YYYY)** 12-2003

**2. REPORT TYPE** Final

**3. DATES COVERED (From - To)**

**4. TITLE AND SUBTITLE**
Technology Demonstration of Wet Abrasive Blasting for Removal of Lead- and Asbestos-Containing Paint

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER** 063728A

**6. AUTHOR(S)**
Timothy Race, Ashok Kumar, and L. D. Stephenson

**5d. PROJECT NUMBER** 002

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER** CF-M B101

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ERDC/CERL TR-03-32

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Headquarters, Department of the Army
Attn: DAIM-FDF
600 Army Pentagon
Washington, DC 2031-0600

**10. SPONSOR/MONITOR'S ACRONYM(S)**
DAIM- FDF

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**14. ABSTRACT**

A group of 1940s-era concrete block buildings at Fort Carson, CO, must be demolished, but they are coated with lead-based paint containing asbestos filler that must both be disposed of as hazardous waste. In order to decrease waste disposal costs, an improved method was needed to remove both coatings while rendering the lead-containing debris non-leachable). This technology demonstration showed that wet blasting using an engineered abrasive can safely and effectively remove lead- and asbestos-containing paint from exterior concrete masonry unit walls, producing an asbestos-free substrate ready for conventional demolition or renovation. The combination of water injection into the blasting process and a ventilated containment structure produced zero visible emissions and complied with applicable asbestos and lead air quality standards. Use of the chemical stabilizing product Blastox® in the dry blast media eliminated the toxic lead characteristic from the paint removal waste. The estimated unit area cost (UAC) of the demonstrated technology was $7.87/sq ft, compared with an average contracted cost of $8.15/sq ft. Elimination of the hazardous waste stream provides the user with other benefits, including reductions in permitting, storage, and handling costs. The primary limitation of the technology is substrate damage caused by the aggressiveness of the abrasive.

**15. SUBJECT TERMS**
Lead-based paint, asbestos, paint removal, coatings, hazardous wastes, Blastox, Fort Carson, CO

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | Ashok Kumar |
| Unclassified | Unclassified | Unclassified | SAR | 41 | 19b. TELEPHONE NUMBER (include area code) 217/352-6511 |

NSN 7540-01-280-5500
Prescribed by ANSI Std. 239.18

Standard Form 298 (Rev. 8-98)