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Cost and Performance Report

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Thermal Spray Removal of Lead-Containing Paint of Steel Structures

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LIST OF ACRONYMS

ACGIH	American Conference of Government Industrial Hygienists
ASTM	American Society for Testing and Materials
CERL	Construction Engineering Research Laboratories
CO	Carbon Monoxide
CHPPM	Center for Health Promotion and Preventive Medicine
DoD	Department of Defense
DTSC	Department of Toxic Substances and Control
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air
MCBH	Marine Corps Base, Hawaii
Mil	One thousandth of an inch
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
OSHA	Occupational Safety and Health Administration
Pb	Lead
PEL	Permissible Exposure Limit
POM	Program Objective Memorandum
PM	Particulate Matter
RCRA	Resource Conservation and Recovery Act
SERDP	Strategic Environmental Research and Development Program
SSPC	Steel Structures Painting Council
TCLP	Toxicity Characteristic Leaching Procedure
TLV	Threshold Limit Value
TSV	Thermal Spray Vitrification
USACE	United States Army Corps of Engineers
USACERL	United States Army Construction Engineering Research Laboratories
USACHPPM	United States Army Center for Health Promotion and Preventive Medicine

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Points of contact can be found in Appendix A.

Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

In the past, red lead primer has been used on many steel structures to control corrosion. Commonly used structures in the Department of Defense (DoD) include bridges, aircraft hangars, water storage tanks, metal buildings, fire hydrants, and structural steel. When the lead-based paint cannot be overcoated because of peeling, it must be removed before repainting. The use of conventional abrasive blasting for removal requires a tight containment structure to keep the lead dust from contaminating air, soil, and water. Increased worker protection is required inside these containment structures because of high dust concentrations. The personal protective equipment (PPE) is time-consuming to put on and cumbersome to use, which reduces worker productivity and drives up costs.

This Environmental Security Technology Certification Program (ESTCP) project demonstrated the Thermal Spray Vitrification (TSV) process, in which molten glass is sprayed on the coated structure. The glass encapsulates the lead-containing paint and falls off on cooling because of the thermal stresses. The collected waste is vitrified so that it can be disposed of as non-hazardous waste or recycled into value-added products.

The demonstrations and validations of the TSV process were conducted on a bridge at the Rock Island Arsenal, Illinois in 1997 and on an aircraft hangar door at the Marine Corps Base at Kaneohe Bay, Hawaii in 1998. These demonstrations met all of the performance objectives, which were to: (1) remove lead-containing paint from steel structures in the field, (2) meet all applicable environmental standards, (3) meet all applicable worker health and occupational safety standards, (4) enable recoating of the substrate using a surface-tolerant coating system, and (5) collect data and estimate production rates.

The production rate of the TSV process for the Rock Island Arsenal bridge was estimated at 30 square feet per hour (or 600 mil-square foot paint removed per hour), and for the Kaneohe Marine Corps Base aircraft hangar door was estimated at 35 square feet per hour (or 700 mil-square foot paint removed per hour). The cost was estimated to range from $3.50 to $9.50 per square foot, with a typical average cost of $5.00 per square foot. By comparison, the cost range for conventional abrasive blasting is $5 to $18 per square foot, with a typical average of $8 per square foot. Residual lead levels after completion of the TSV process were 1.0 to 2.4 mg/cm^2. The major advantages of the TSV process are the reduced exposure of workers to toxic dust and the elimination of hazardous waste, the disposal of which costs approximately $4 per square foot of depainted surface.

A niche market is anticipated for the TSV process. This market would include surface preparation for zone painting on large bridge structures or for small fixed structures such as fire hydrants, where the cost of the containment structure required for conventional technologies would be a large part of the overall cost. The waste glass from the TSV process potentially can be recycled using commercial processes that convert the slag waste into non-hazardous, value-added glass or ceramic products such as abrasives, construction materials, and refractory insulating materials. DoD-wide savings over the next 20 years are estimated at over $30 million.

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2.0 TECHNOLOGY DESCRIPTION

Red lead primer has been used on many steel structures to control corrosion. When lead-based paint shows evidence of peeling, removal is required. A containment structure is required to keep the lead dust from contaminating the air, soil or water during conventional removal. Inside tight containment structures, increased worker protection is required due to the higher dust concentrations. This reduces worker productivity.

This Environmental Security Technology Certification Program (ESTCP) project demonstrated and validated the use of the thermal spray vitrification (TSV) process to remove lead-based paint from Department of Defense (DoD) steel structures. The U.S. Army (Ref. 1) patents this technology. In the TSV process, specially formulated iron silicate glass is applied to the painted steel substrate using a thermal spray gun. The molten glass reacts with the paint and the lead from the paint adheres to the glass surface. Lead ions are absorbed into the molten glass as it spreads over the surface and are trapped within the silicate matrix. The glass cracks and falls off the substrate upon cooling. The waste glass is remelted to complete the vitrification process and the end-product is classified as non-hazardous.

The TSV process uses commercially available thermal spray equipment. The individual system components include the hand-held torch, powder feeder, gas manifold, gas flow controllers, and pressure regulators. The system is connected using hoses and is shown schematically in Figure 1. The pressure and flow of all the gases are controlled by regulators and flow meters. These gas flow parameters are set to predetermined values and the gases are mixed and combusted in the torch nozzle, where the powder is introduced. The resulting flame temperature is in excess of 2000°C (3600°F). Powder flow is controlled by the powder feeder. The powder melts in the flame as it is propelled toward the substrate. The iron boro-silicate glass composition was developed by the US Army Construction Engineering Research Laboratories (CERL) in conjunction with the Department of Energy, Savannah River Technology Center. The glass composition produces a stable and durable waste product that can immobilize up to 25 percent of its own weight of lead. This waste glass has a Toxicity Characteristic Leaching Procedure (TCLP) value for lead of less than 5 parts per million (ppm).

Caution should be used to prevent warping of materials when applying a large amount of heat to steel substrates of complex geometry. The heat of the TSV process can cause warping of steel with cross-sectional thickness of less than 3.63 mm (0.143 in.). This issue was addressed in the demonstration by employing a commercial device that uses compressed air and water. The air-water mist is directed on the backside of thin steel sections during processing to keep it cool to reduce or eliminate warping. The air-water mixture is set to cool without condensing water on the surface.

The glass fragments from the TSV process fall into a sheet metal pan for collection. In some areas, the glass has to be removed with a blow from a chipping hammer. A vacuum-equipped needle gun with high-efficiency particulate air (HEPA) filter can be used to clean crevices and remove loose scale and other loose detrimental foreign matter.

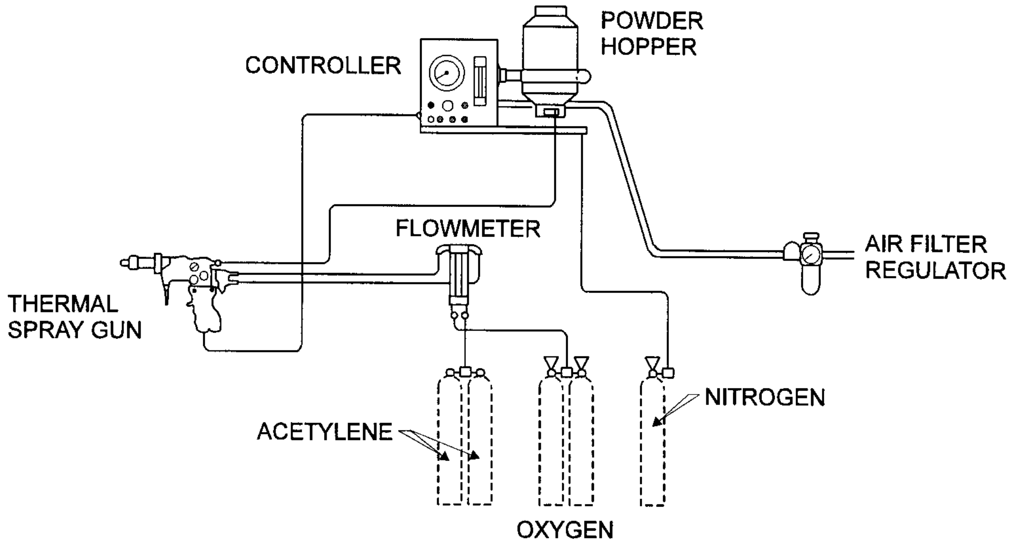

Figure 1. Schematic Diagram of TSV Equipment

The collected glass and waste is remelted in a furnace on-site to complete the vitrification process. The final product has a TCLP lead leachate concentration of less than 5 ppm. The remelt process may be repeated if the glass waste does not pass the required TCLP criterion.

A proof-of-principle field test of the TSV process was conducted in June 1996 at the Triborough Bridge in New York City by the Thermal Spray Laboratory of the State University of New York at Stony Brook. The paint was successfully removed, and the resulting surface was recoated with a surface-tolerant coating system. Worker exposure did not exceed any applicable airborne standard.

The TSV process removes paint and restores the surface of steel to the profile as it was before painting. Rust is also removed in the TSV process leaving a dull finish that meets the Steel Structures Painting Council (SSPC) Specification SSPC 3, "Power Tool Cleaning." This surface finish is acceptable for surface-tolerant coatings in atmospheric exposure. The life of the newly coated surface should provide 25-year performance.

The TSV process is limited to the removal of lead-containing paint from steel structures. This technology is not applicable to removing lead-containing paint from wood, concrete or masonry structures because of the relatively high process temperature and the potential to damage the substrate.

Overcoating, which is defined as the practice of painting over existing coating as a means of extending service life, is much cheaper than complete removal of lead-based paint. However, overcoating has significant risks of failing catastrophically or not providing the desired protection. To determine the feasibility of overcoating, acceptance criteria are presented here for visual assessment of percent rusted area, adhesion and film thickness, and patch-testing.

Maximum recommended levels of rusting are 10 % (rust rating of 4) for typically degraded areas and 17% (rust rating of 3) for most severely degraded points of the structure. The work necessary to clean and paint structures corroded to this degree approaches that required for removal, and the performance of the applied overcoat system is unlikely to be as good as that of a new paint system. Therefore, these structures would be excellent candidates for thermal spray removal.

The risk associated with overcoating can be determined by measuring the thickness and adhesion of the existing coating. The risk of overcoating failure increases with increasing film thickness and decreasing adhesion. For example, if the existing coating is 20 mils thick and the adhesion, as determined by the American Society for Testing and Materials (ASTM) D3359 test, is 1A or 1B, then the risk is high. These coatings would be good candidates for thermal spray removal.

The ASTM test D 5064 and SSPC Guide 9, section 6.2.2 provide details of patch testing. Ideally the patch test period should span at least one winter. Delaminated test patches imply a very high risk. An intermediate level of risk is indicated by poor or reduced levels of inter-coat or base-coat adhesion. These would be good candidates for thermal spray removal.

Surface preparation for overcoating is very critical and should be selected to minimize damage to the aged coating while providing a clean surface free of contaminants, corrosion, and poorly adherent coating. Sweep and brush-off blasting may disrupt the adhesion or fracture the aged coating, which may lead to failures of the overcoat system. High-pressure water cleaning coupled with vacuum-shrouded, power-tool cleaning may be used for surfaces with rusting greater than 3% but less than 10%. Removal by abrasive blasting or thermal spray removal is recommended if the rusting is more than 10%. The relative cost of containment structure is lowered if the application is large, defined as surface area greater than 10,000 sq. ft. Smaller structures are good candidates for thermal spray removal.

Another innovative lead-based paint removal process is currently being investigated in a research project funded by the DoD Strategic Environmental Research and Development (SERDP) program. The use of microwave technology, which may avoid some of the warping associated with the TSV technology, is promising.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The main performance objectives for this series of demonstrations were to:

(1) Remove lead-containing paint from a steel structure,
(2) Meet all applicable environmental standards,
(3) Meet all applicable worker health and occupational safety standards,
(4) Be able to recoat the substructure using a surface-tolerant coating system, and
(5) Collect data to estimate the production costs.

3.2 PHYSICAL SETUP AND OPERATION

The first site was the viaduct bridge located at the Rock Island Arsenal, Illinois. The viaduct bridge connects the Rock Island Arsenal and the City of Rock Island and has two lanes for vehicle traffic. The bridge design is typical of Federal highway and Army bridges. It was coated with a lead-containing primer and alkyd topcoats. The demonstration of the TSV process was conducted in 1997 on a section of a horizontal steel beam below the traffic deck of the bridge, on the first three panels of the eastern- most bridge girder on the north (river) side of Pier No 8. Scaffolding was constructed to provide access to the girder. A ramp provided access to the scaffolding from the levy that abuts Pier No. 8. Figure 2 is a photograph of the site.

The Rock Island Bridge demonstration required the construction of a temporary scaffolding to permit worker access to the underside of the bridge. The construction specification called for containment to comply with the requirements of Steel Structures Painting Council (SSPC) Guide 6, Class 3C. The contractor provided full containment in accordance with SSPC 6, Class 1C.

Electrical power was supplied by a portable, gasoline-powered generator for the task lighting and for the 10-micron-particulate-matter (PM-10) air monitors. Compressed air was provided for the powder feeder, the HEPA equipped power tools, and for the paint spray gun. Bottles of oxygen, and acetylene used by the TSV process were stored in a secure fenced area on the land side of Pier No. 8. The air compressor, electrical generator, and air filtration unit were deployed on top of the levy near the work site. The powder feeder was placed on the scaffolding during application of the thermal spray process. Storage sheds were also placed on the levy near the work site.

The second site was a hangar door, representative of hangars in the DoD, located on a portion of Hangar 3, Building 103 at the Marine Corps Base, Kaneohe Bay, Hawaii (MCBH). The TSV process was applied to the flat outside door surface and to flat surface and beams on the interior of the door. The hangar was undergoing rehabilitation, which provided a challenge for lead-containing paint abatement because the floor was newly refinished adjacent to the interior of the hangar door. Figure 3 is a photograph of the door interior.

Figure 2. Rock Island Bridge Showing Area of TSV Demonstration

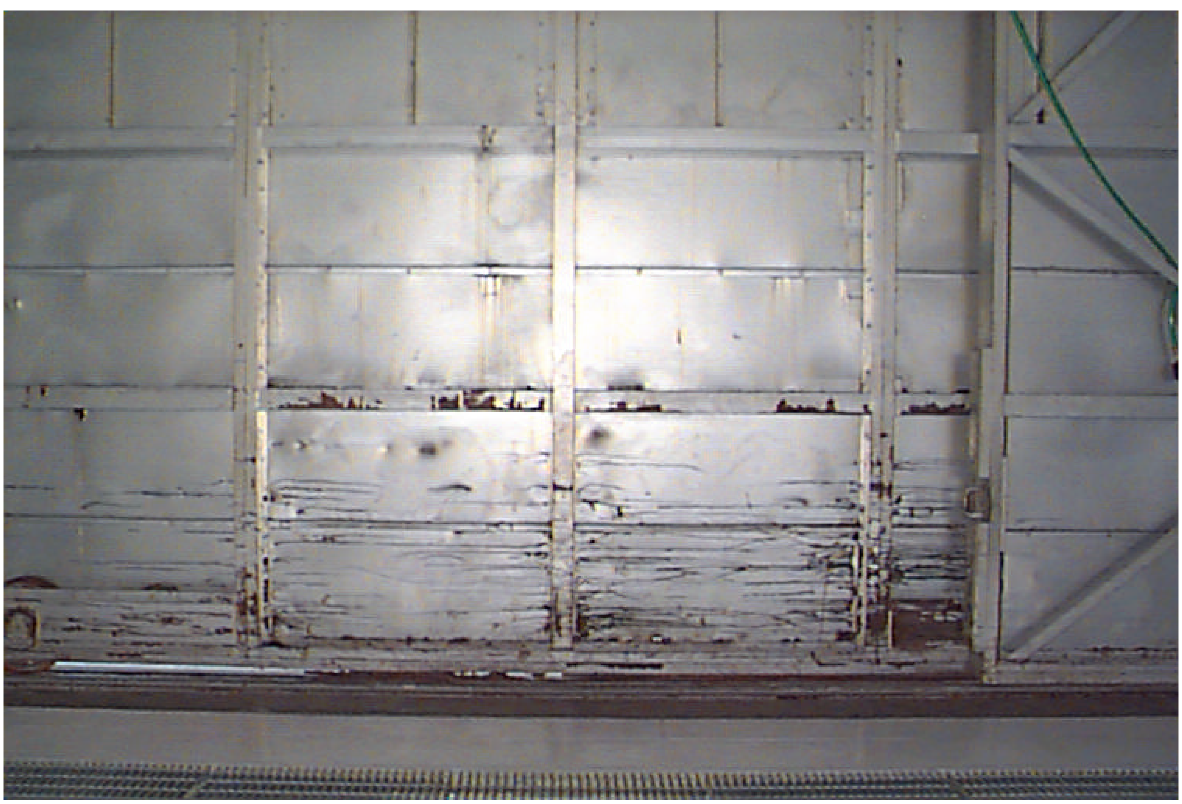

Figure 3. Hangar Door Interior at the Marine Corps Base, Hawaii

The demonstration of the TSV process was conducted in 1998, at ground level without the need for scaffolding or ladders. This hangar was active and permission was obtained through the MCBH Facilities Department to use the 110V power and compressed air available in the hangar. Oxygen, acetylene and propane for the TSV process were obtained through a local vendor and secured on a bottle rack during the working day. The gas location remained fixed for the duration of the demonstration.

The powder feeder and thermal spray torch were located adjacent to the work area during the TSV processing. For the inside of the door, the equipment was located inside the hangar. For processing outside, the equipment was located on the outside of the hangar door. The equipment was only moved once for the demonstration.

The remelting process for each demonstration consisted of the following steps:

1. Add the waste from the TSV process to the furnace until full.
2. Heat the furnace to at least 800°C (1470°F) and maintain for 3 hours.
3. Stir every 15 minutes after melting occurs.
4. Shut off the heat and cool the waste.
5. Reheat the furnace to at least 800°C (1470°F) and maintain for 2 hours.
6. Pour or dip the molten glass from the furnace into water.
7. After cooling, remove the glass from the water using separate utensils to prevent cross contamination.

8. Test the cooled waste material using TCLP analysis.
9. Dispose of the glass through appropriate channels when the material passes TCLP analysis.

3.3 MONITORING PROCEDURES

Evaluation of the existing paint system included dry film thickness measurement using American Society for Testing and Materials (ASTM) D 1186 "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base." The adhesion of the existing paint system was determined using ASTM D 3359 "Standard Test Method for Measuring Adhesion by Tape Method." Personnel from the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) sampled the existing paint system and performed total metal and TCLP analysis.

Following the TSV process, and prior to repainting, the surface profile was compared to visual standards from the SSPB-VIS-1-89 "Visual Standards for Abrasive Blast Cleaned Steel (Standard Reference Photographs)." The profile was also evaluated using ASTM D 4417 "Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel." Following repainting, the paint was inspected in accordance with the requirements for Paint System No. 16 in the USACE Guide Specification CEGS 09940, "Painting: Hydraulic Structures."

Air sampling was conducted for analysis of metals, dust, crystalline silica, and combustion products. Upwind air samples were used to assess background chemical concentrations. Personal air samples were used to assess actual exposures for comparison to occupational airborne exposure limits. Downwind air samples were used to assess diluted chemical concentrations downwind from the plume to determine potential exposures to others in close proximity. Source air samples were used to capture the rising plume to assess potential worst-case exposures and to ascertain the amount of dilution occurring at other sampling sites.

Occupational exposures were compared to the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PEL) and American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV). Metal leachate from the solid vitrified paint remelt samples were compared to EPA Toxicity Characteristic Leaching Procedure regulatory levels (i.e., Title 40 Part 261.24, Toxicity Characteristic, Table 1 - Maximum Concentration of Contaminants for the Toxicity Characteristics).

3.4 ANALYTICAL PROCEDURES

The personal air samples and area air samples were analyzed for lead according to National Institute for Occupational Safety and Health (NIOSH) Method 7300. The respirable dust level was measured by NIOSH Method 600. The TCLP was performed in accordance with EPA Method 1311. The lead content of the original coatings and the residual lead on the surface after completion of the TSV process were measured using X-ray fluorescence.

3.5 DEMONSTRATION SITE/FACILITY BACKGROUND AND CHARACTERISTICS

Site selection for the demonstration of the TSV process was based on the following requirements:

(1) A steel structure with lead-containing paint,
(2) Structural design typically found on other DoD installations,
(3) Paint system similar to that used at other DoD installations, and
(4) A site willing to actively participate and assist in the demonstration.

The first demonstration, conducted on a steel viaduct bridge at the Rock Island Arsenal, IL, and the second demonstration, conducted on a hangar door, on a portion of Hangar 3, Building 103 at the Marine Corps Base, Hawaii both met these requirements.

4.0 PERFORMANCE ASSESSMENT

The demonstration of the TSV process successfully met all the performance objectives, which were to: (1) Remove lead-containing paint from steel structures in the field, (2) Meet all applicable environmental standards, (3) Meet all applicable worker health and occupational safety standards, (4) Re-coat the steel substrate using a surface-tolerant coating system, and (5) Collect data and estimated production rates.

The initial goal was to reduce the lead on the steel surface to less than 1 milligram per square centimeter but this required many passes of the torch and a lot of heat, which could have damaged the substrate. Evaluation of the removal process during the demonstration showed that even lead levels this low could still create hazardous levels of lead dust in containment structures, which would be required if abrasive blasting were used during the next painting cycle. Thus, creating a surface to which surface-tolerant coatings could satisfactorily adhere, was established as a qualitative goal.

The remelted waste successfully met EPA regulatory guidelines for leachate (using TCLP), but required a total remelt time of 5 hours.

4.1 ROCK ISLAND BRIDGE DEMONSTRATION

Evaluation of the existing paint system was conducted by personnel from the Paint Technology Center at USACERL. This included dry film thickness and adhesion measurement. The measured thickness of the existing paint on the flat vertical web of the bridge girder ranged from 3.3 to 5.9 mils. The existing paint was thicker on the vertical ribs and the lower horizontal flange, ranging up to 17.8 mils. The existing paint was well adhered to the substrate. Personnel from USACHPPM sampled the existing paint system and found it contained from 106,000 to 495,000 mg/kg Pb. The vitrified paint contained up to 48,200 mg/kg Pb.

The TSV process was used on a total of 180 square feet of painted area of the bridge, on three panels of the bridge girder.

During the initial application of the TSV process, it was noted by the operator that the vertical web of the beam was warping from the heat of the process. The application of the TSV process was immediately stopped and the degree of warping was measured and found to range up to 3/8 inch. A structural engineer from the Corps of Engineers, Rock Island District inspected the beam and concluded that the warping did not adversely impact the structural integrity of the beam or the bridge. The maximum temperature recorded was 273 °C (523 °F) and 322 °C (611 °F). The TSV procedure was modified to eliminate the use of a separate torch to preheat the substrate. The thermal spray torch was used in a more controlled manner to preheat the substrate and the amount of warping was minimized.

Following application of the TSV process, the surface met the SSPC requirements SP1 and SP3, and was suitable for repainting with a surface-tolerant coating system. The surface profile was measured using ASTM D 4417 and ranged from 2.0 to 3.0 mils.

The primer coat was a Sherman Williams industrial coating SSPC 25 red primer. The topcoat was a Sherman Williams industrial enamel No. 2.16. This is a medium oil, alkyd, all purpose enamel designed for new construction and maintenance work and provides performance comparable to products formulated to Federal Specification TT-E-489. The measured thickness of the dried primer ranged from 1.7 to 3.4 mils and was on average 3.0 mils. The measured thickness of the completed coating system primer plus top coats ranged from 5.4 to 8.4 mils and was on average 6.9 mils.

X-ray fluorescence analysis determined that the lead concentrations of the original coating ranged from 4.7 to 5.8 mg/cm^2. The measured lead concentration remaining on the steel surface after TSV was found to range from 1.0 to 2.1 mg/cm^2.

The results of 493 samples of metals, dust, and silica were reported by CHPPM (Ref. 6).

CHPPM concluded that the potential to exceed current airborne occupational health standards for some chemicals [Pb, respirable and total dust, (additive effects of CO + NO), and NO_2] is high whenever vitrification is conducted in areas where the plume is inhibited. This would include enclosed/containment structures (such as at the Rock Island bridge demonstration) and in unenclosed areas such as under a bridge or where there is a roof/ceiling above the plume, etc. The hazard will be less whenever vitrification is conducted in areas where the plume is uninhibited or a heat shield is used. The hazard will be least where the plume is uninhibited and a heat shield is not used. The total containment was found to inhibit the plume and contribute to dead air space that allowed airborne materials to concentrate, even though there was positive pressure air flow through the containment structure. CHPPM also concluded that there is the potential to exceed current airborne occupational health standards for Pb and possibly CO when working around the glass remelter.

4.2 KANEOHE BAY HANGAR DOOR DEMONSTRATION

The TSV process was used on a total of 171 square feet of painted area on the hangar door. This consisted of the flat outside door surface and flat surface and beams on the interior of the door.

The existing paint coating consisted of several layers of paint from various overcoats. The dry film thickness on the exterior door skin ranged from 17.8 to 23.9 mils with an average of 20.76 mils. The thickness on the interior door skin ranged from 4.9 to 8.8 mils with an average of 7.1 mils. The paint on the frame surfaces ranged from 3.2 to 17.3 mils with an average of 10.27 mils. The paint system on the exterior skin contained an average of 2.57 mg/cm^2 of lead measured by an X-ray fluorescence instrument. The paint system on the interior skin contained an average of 5.5 mg/cm^2 of lead. The paint of the frame members contained an average of 12.89 mg/cm^2 of lead.

For hangar doors, a separate torch is not required to pre-heat substrates because the substrate is relatively thin. The thermal spray torch provided all the heat necessary to perform the TSV process.

The interior of the door was processed first. The sheet metal skin had a thickness of approximately 3.63 mm (0.143 inches) and therefore, the water mist system was set up on the outside of the door.

The set-up time for the water mist system was less than 15 minutes for each side of the door. The minimal warping disappeared upon cooling. The beams did not warp during processing and therefore did not require any mist cooling. During interior processing, the exterior paint softened and peeled off easily. Most of this paint could be removed easily with a paint scraper. This paint was processed in the furnace along with the other waste from the TSV process.

Two applications of the TSV process were used on most areas of the interior of the door. On the top of the beams where the paint was thicker, three applications of the TSV process were used. Only one application of the TSV process was used on the exterior of the door.

The surface was cleaned with a needle gun to remove any loose debris on the surface. This operation was performed in less than 1 hour for the TSV processed area.

The surface was primed with Rustbond Penetrating Sealer SG from Carboline Corp., St. Louis, MO. The top coat for the interior was Carbomastic 15 Low Odor and the top coat for the exterior was Carboline 3359, a water-borne acrylic. The top coat choice was recommended by the local Carboline representative and approved by CERL. The contractor followed the manufacturer's recommendations for mixing and applying the paint. During paint application, the temperature was above the minimum and humidity was below the maximum manufacturer's recommendations.

The personal air samples and area samples were analyzed for lead according to NIOSH Method 7300. The results of the testing were time-weighted averages for eight hour exposures. The lead level in the personal air sample from the worker performing the TSV process was 50.9 micrograms/m^3. The lead level in the personal air sample for the person performing the needle gun operation was $<$20.4 micrograms/m^3. The level of lead behind the TSV operator, inside the controlled area was $<$2.1 micrograms/m^3. The lead concentration 20 feet downwind from the TSV process directly outside the control area was 1.11 micrograms/m^3. For reference, the personal exposure limit (PEL) for lead is 50 micrograms/m^3. The results of personal air samples taken during the peeling and scraping of the paint on the backside were far less, since the paint formed a paste with the mist. The respirable dust level was measured using the NIOSH Method 600. The respirable dust for the operator performing the TSV process was 0.4 mg/m^3.

The lead concentration on the interior skin after TSV processing and before needle gun cleaning averaged 1.465 mg/cm^2. The lead concentration on the framing after the TSV processing and before needle gun cleaning averaged 2.87 mg/cm^2. The lead concentration on the exterior skin after needle gun cleaning averaged 1.05 mg/cm^2. The lead concentration on the interior skin after needle gun cleaning averaged 1.14 mg/cm^2. The lead concentration on the framing after needle gun cleaning averaged 2.44 mg/cm^2. The remelted waste successfully met EPA regulatory guidelines for leachate (using TCLP).

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5.0 COST ASSESSMENT

In field trials, operators removed paint with a thickness of 0.25 to 0.64 mm (0.010 to 0.025 in) in two applications of glass at a rate of 30 sq. ft./hr for the Rock Island bridge demonstration, and 35 sq. ft./hr for the Marine Corps Base hangar door demonstration.

Table 1 contains cost projections for a 1,000-ft^2 application of the TSV process, developed from the cost data obtained from the two demonstrations. The capital costs for this work are relatively low and the maintenance costs only require some consumable parts and a small amount of time to replace the parts. The major parts on the equipment list will be of service for 10 or more years. The consumable parts last over 50 hours of flame-on time. The consumable parts can be replaced in 30 minutes or less. The labor rates are based on the rates paid by the contractor that did the demonstration and are denoted "Bridge" for the Rock Island demonstration and "Hangar" for the Marine Corps Base demonstration. The contractor at Rock Island used a painter to apply the glass for the TSV process, while the contractor for the Marine Corps Base used the foreman to apply the glass. The labor to remelt the glass is estimated at 8 hours for both demonstrations using a production type furnace. It is included (with clean up time to clear loose paint debris) in the TSV process time because the glass remelt process does not require a full time attendant. The total amount of glass used during these demonstrations is conservatively estimated at between 0.5 and 0.75 lb/sq. ft. For larger areas, and by using a combination of virgin glass and recycled glass, the cost of the glass can be as low as $0.50/lb.

The production rates observed in the demonstrations were the basis for the costs developed in Table 1. For the bridge, the average production rate for removing a 20 mil thick degraded lead-based paint was 600 mils-sq. ft./hour, based on 2 spray passes and 30 sq. ft./hour. For the hangar door, the average production rate for removing a 20 mil thick degraded lead-based paint was 700 mils-sq. ft./hour, based on 2 spray passes and 35 sq. ft./hour.

To allow for cost sensitivities due to the complexity of an application, costs were also developed for a production rate of 300 mils-sq. ft./hour for a bridge and for a production rate of 1,000 mils-sq. ft./hour for a hangar door. These additional rates represent the extremes that are likely to be encountered, and allow development of a cost range for the TSV process. The typical average cost of using the TSV process is estimated to be approximately $5.00 per sq. ft. for steel structures coated with lead-based paint, with a cost range of $3.50-9.50 per sq. ft. depending on the complexity of the surfaces. The more complex the surface, the more time and glass must be used to remove the paint.

By comparison, the cost of removal and disposal of lead-based paint from flat surfaces on steel structures is estimated to be $5-18 per sq. ft. using abrasive blasting in a containment structure. This cost can vary up to $100 per sq. ft. depending on the area, complexity and other requirements such as working over water or in the presence of machinery. The disposal cost of the hazardous waste alone is about $4 per sq. ft.

The Federal Highway Administration and the National Transportation Research Board have conducted studies on the cost of removing lead-based paint from highway bridges (Refs. 7 and 8). The costs of various conventional paint removal technologies found by these studies are shown in

Table 2. Further, the Army Corps of Engineers district engineers indicated that the cost of lead paint removal using existing technologies was more than \$20 per sq. ft. for Lock and Dam No. 13 on the Mississippi River, which was a relatively difficult application.

The projected cost range for the TSV process of \$3.50 to \$9.50 per sq. ft., with a typical average cost of approximately \$5.00 per sq. ft., is lower than the average costs of other technologies, which range from \$7.00 to \$13.00 per sq. ft.

Table 1. Cost Analysis for TSV Process (for 1,000 ft^2 application)

CAPITAL COSTS	
Thermal Spray Gun	$550
Powder Feeder	$1,550
Flow Meters, Air Filter	$300
Hoses and Miscellaneous Fittings	$200
EQUIPMENT TOTAL	**$2,600**

OPERATIONAL COSTS (for 1,000 ft^2 application)								
	Rate ($)		**Hours**		**Cost**			
PAINT REMOVAL PRODUCTION RATE (mils-ft^2/hr)	**Bridge**	**Hangar**	**Bridge**	**Hangar**	**Bridge**	**Bridge**	**Hangar**	**Hangar**
					300[1]	**600[2]**	**700[3]**	**1,000[4]**
ACTIVITY								
STARTUP								
Foreman	$27.43	$25	8	8	$219	$219	$200	$200
Laborer	$24.62	$21	8	8	$197	$197	$168	$168
Collection of Glass					$100	$100	$100	$100
Activity Subtotal					**$516**	**$516**	**$468**	**$468**
TSV PROCESS								
Labor								
Foreman	$27.43	$25	40[2]	39[3]		$1,097	$975	
	$27.43	$25	80[1]	27[4]	$2,194			$675
Painter	$24.62	$23	34[2]	0[3]		$837	$0	
	$24.62	$23	68[1]	0[4]	$1,674			$0
Laborer	$22.73	$21	8[2]	8[3]		$182	$168	
	$22.73	$21	32[1]	6[4]	$727			$126
Materials								
Glass Powder					$1,500	$500	$500	$500
Utilities					$400	$200	$200	$200
Miscellaneous					$100	$100	$100	$100
Equipment Depreciation (10 yr., 60%)					$10	$10	$10	$10
Consumables					$350	$350	$175	$175
Monitoring					$400	$400	$250	$250
Waste Transportation					$100	$100	$125	$125
Non-Hazardous Waste Disposal					$50	$25	$0	$0
Hazardous Waste Disposal					$100	$100	$200	$200
Activity Subtotal					$7,605	$3,901	$2,703	$2,361
DEMOBILIZATION								
Foreman	$27.43	$25	8	8	$219	$219	$200	$200
Laborer	$22.73	$21	8	8	$182	$182	$168	$168
Activity Subtotal					**$401**	**$401**	**$368**	**$368**
SUB-TOTAL					**$8,522**	**$4,818**	**$3,539**	**$3,197**
OVERHEAD/PROFIT (10%)					**$852**	**$482**	**$354**	**$320**
TOTAL COST (1,000 ft^2)					**$9,374**	**$5,300**	**$3,893**	**$3,517**
COST/ft^2					**$9.37**	**$5.30**	**$3.89**	**$3.52**

NOTES:
1. Lower bound (extrapolated from actual demonstration production rate for bridge)
2. Based on actual demonstration production rate for bridge
3. Based on actual demonstration production rate for hangar door
4. Upper bound (extrapolated from actual demonstration production rate for hangar door)

Table 2. Comparative Costs for Lead-Containing Paint Removal

Technology	Range $/sq. ft.	Average $/sq. ft.
Thermal Spray Vitrification (Projected)	3.50 - 9.50	5.00
Abrasive Blasting	5.00 - 18.00	8.00
Wet Abrasive Blasting	5.00 - 20.00	12.00
Vacuum Blasting	4.00 - 20.00	10.00
Water Blasting	4.00 - 20.00	13.00
Water Blasting with Abrasive Injection	4.00 - 19.00	9.00
Power Tool Cleaning To Bare Metal	5.00 - 15.00	7.00

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

There are several factors that influence the cost and performance of the TSV process. The condition and thickness of the paint determines the amount of preheating and the number of glass layers that must be applied to remove all the paint to prepare the surface for recoating with a surface tolerant paint. The complexity of the structure also negatively influences the productivity of the process. Structures with excessive bends, corners, crevices and recessed areas are more difficult to access and may require additional time for depainting and for final cleanup before repainting.

6.2 PERFORMANCE OBSERVATIONS

For lead-containing paint abatement, the TSV process reduces the amount of hazardous lead dust to levels that permit the process to be performed without special containment. The exposure levels for the TSV process are less than for other processes, such as abrasive blasting. Therefore, the protection required for workers also may be reduced.

The waste from the process is substantially less than with other processes and this waste is non-hazardous. The TSV process produces approximately one-half to three-quarters of a pound of non-hazardous waste for each square foot of lead-containing paint removed.

The TSV process produces a surface that needs little additional preparation for painting. These demonstrations utilized a needle gun to remove any loosely adhered glass materials from the surface.
The non-hazardous waste can be disposed of in a landfill or recycled for several uses including abrasive blast media, grit for nonskid surfaces, grit for roofing shingles or as sprayable glass for the TSV process.

The TSV technology can be employed for small lead-containing abatement jobs with quick set-up times and low set-up costs. Examples of this type of application include highway expansion joints, bridge bearing areas and small freestanding infrastructure items such as fire hydrants.

6.3 OTHER SIGNIFICANT OBSERVATIONS

Commonly used lead-containing paint abatement technologies include abrasive blasting inside containment, chemical strippers, closed-cycle ultra-high pressure water, and wet abrasive blasting with a chemical stabilizer. The TSV process has advantages over each of these methods.

Among the advantages of the TSV process is the elimination of the need to build and use a containment structure. Containment structures needed for other lead-containing paint abatement methods are expensive and time-consuming to fabricate. Monitoring data collected during previous demonstrations shows that the potential is small to generate airborne lead concentrations in excess of regulatory limits when the plume from the process is inhibited. When the TSV process is used in an enclosed or semi-enclosed area such as between beams under a bridge, the workers should use appropriate respirators. The potential contaminants in these areas include lead dust, other fine particles from the paint and additive effects of CO, NO, and NO_2.

The TSV process is limited to the removal of lead-containing paint from steel structures. This technology is not applicable to remove lead-containing paint from wood, concrete or masonry structures because of the relatively high temperature of the process.

6.4 REGULATORY AND OTHER ISSUES

The State of Illinois Environmental Protection Agency (IL EPA) was contacted by the Corps of Engineers, Rock Island District regarding the on-site remelting of the vitrified waste during the demonstration. The Corps of Engineers Rock Island District informed IL EPA about the scope and purpose of the TSV demonstration project, as well as about previous laboratory and field test results. IL EPA, Division of Air Pollution Control, classified the TSV process, including the glass remelting, as a repair/ construction activity and regulated it as they would a lead-containing-paint cleaning operation. The IL EPA does not require air permits for paint cleaning activities (such as the project to remove lead-containing paint from a water tower at the Rock Island Arsenal). The IL EPA stated that the Rock Island demonstration did not require a permit, based on the type and amount of work. Letters were sent by the Corps of Engineers Rock Island District to IL EPA, Division of Air Pollution Control, stating that permits were not required. The contract called for the on-site remelting of the glass in order to make the waste non-hazardous and permit disposal as a special waste in an industrial landfill. Remelting the glass for a minimum of five hours resulted in a non-hazardous waste as determined by TCLP analysis.

Regulatory acceptance for the Kaneohe Bay hangar door demonstration was based on successfully producing non-hazardous waste, and also on the air quality data from the demonstration of the TSV process at the Rock Island Arsenal, Rock Island, IL (Ref. 9) and the data from the CHPPM report (Ref. 6). This information was forwarded to the appropriate agencies in Hawaii with the assistance from the Facilities Department at the Marine Corps Base, Hawaii and the Naval Facilities Engineering Command, Pacific Division.

The TSV process involves both removal and subsequent remelting onsite of the glass. This is viewed by the EPA as a single operation and not a waste treatment operation. This is based on the IL EPA, Division of Air Pollution Control classifying the TSV process as a repair/construction activity and regulating the process as a lead-containing paint cleaning operation.

The contract required on-site melting of the glass to complete the TSV process and render the waste as non-hazardous as determined by the TCLP analysis. This was completed and part of the waste was disposed as non-hazardous waste in the Waimanalo Gulch Refuse Facility in Hawaii. The TCLP exhibited less than 5 ppm of lead. Therefore, it was unnecessary to ship the waste to and dispose of it as a hazardous waste at a site in California or Nevada.

The remaining portion of the waste was shipped to Seiler Pollution Control Systems, Inc., Columbus, Ohio to be tested for possible use in their recycling plant operations. Seiler produces glass grit products for non-skid paints, grit blasting, grit for roofing shingles, and other products.

6.5 LESSONS LEARNED

- The amount of heat applied to the substrate during the pre-heat stage of the process must be carefully monitored and controlled to avoid warping the substrate.

- The water misting procedure is successful and should be used on thin sections of steel of less than 0.200 in.

- On-site remelting of the waste required a minimum of five hours at 800 EC (1470 EF) to insure the homogenization of the melt and full immobilization of the hazardous species in order to render the waste non-hazardous as determined by RCRA.

- Proper protection and testing of the workers would be required during any future depainting of a structure to verify that worker exposure to any residual lead on the surface would be below the OSHA regulatory requirement.

- The glass from the thermal spray vitrification process potentially can be recycled using commercial processes that convert the waste into a non-hazardous value added glass or ceramic products such as abrasives, construction material, refractory insulating materials or new glass powder for the thermal spray vitrification process. Recycling would eliminate the need for disposal of the glass waste from the TSV process and the associated disposal costs.

- When the TSV process is used in well-ventilated outdoor areas, the workers should use, at minimum, an NIOSH-certified half-face air-purifying respirator equipped with HEPA filters.
- During remelting of glass, workers do not need to use respirators, although it is recommended that workers should use an NIOSH-certified half-face air-purifying respirator equipped with HEPA filters.

- Testing of workers should be conducted to verify that worker exposure to lead is below OSHA regulatory limits.

- The TSV process at this time is best suited to niche markets where the cost of full containment structures cannot be spread over a large area. Such applications would include zone painting for large structures, and small fixed structures such as fire hydrants, posts, highway overpass rails, fence posts, light stands, fire call boxes, etc.

6.6 SCALE-UP

The estimated surface area of steel structures at Army facilities such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, metal buildings, etc. is about 118 Million square feet. The total surface area of steel structures in the DoD is estimated at 200 Million square feet. The U.S. Army Corps of Engineers also has 275 navigation locks and dams and 383 other dams with service bridges on lakes and reservoirs which have an estimated 100 Million additional square feet of steel. Most of this steel is coated with red lead oxide primer to protect it from corrosion. Over the next 20 years this steel will have to be repainted. The cost analysis, based on data collected during the demonstration, estimated the cost of thermal spray vitrification process to range from \$3.50 to \$9.50 per sq. ft. with an average cost of about \$5.00

per sq. ft. This is $3.00 per sq. ft. cheaper than the currently used abrasive blasting at an average cost of $8.00 per sq. ft. If it is assumed that 10% of USACE structures and 5% of the DoD painted steel structures can use the TSV process, the process is applicable to 20 Million square feet of steel. Based on a benefit of $3 per sq. ft., the estimated savings over the next 20 years to the DoD are $60 Million. In addition, the DoD-wide cost savings that would be realized by using TSV technology rather than abrasive blasting for one-time depainting of DoD fire hydrants is estimated at $6.75 million ($75 per hydrant).

The TSV technology will be implemented by the user via transfer to a commercial firm that performs lead paint removal such as Midwest Foundation, a small business such as Zatorski Coating Co or some other company. The economic viability of TSV will be determined through its success in competitively bid paint removal projects. The Construction Solicitation and Specification prepared for the Rock Island Bridge demonstration can be used as the guidance specification for future lead-containing paint removal projects.

The contractor who performed the Rock Island Bridge Demonstration was obtained through a competitive bid process. The Contractor, Midwest Foundation, Tremont, IL, expressed interest in bidding on future paint removal contracts using the TSV process. Zatorski Coatings Co, East Hampton, CT, a small business that was contracted to conduct the training for the demonstration as well as other companies have also expressed interested in commercialization of the TSV process.

ZCC is actively pursuing markets in the removal of lead-containing paint on fire hydrants and small fixed structures, highway overpass railings and small power plant fixtures such as pump casings, catwalks, railings, posts, etc. The Department of Energy and Westinghouse Corp. is planning a demonstration of the TSV process to remove mixed hazardous and radioactive waste in air ducts at a nuclear facility in Savannah River, GA. This demonstration has a planned start date of March 1999.

Additional Demonstrations for small components at Army installations are planned. Technology Demonstration funds have been authorized in POM (00-03).

To fully commercialize the TSV process, scale up of the glass remelting process will be required. Scale-up would include the use of a larger size glass melter such that the vitrified glass from one day's paint removal could be remelted in one operation. The larger melter would also permit measurement and control of the melt temperature and could provide stirring of the molten glass. Such a melter may require mounting on a truck or a trailer to be deployable in the field.

Alternately, the vitrified glass could be recycled and used as feedstock to produce new glass powder or other glass or ceramic products. According to the recycling exemption of the Resource Conservation and Recovery Act (RCRA), the vitrified product would not be classified as solid waste if it is used or reused as an ingredient in an industrial process to make a product (Ref. 10). Recycled products can be other glass or ceramic products. Potential uses currently under investigation by Seiler Pollution Control System Inc, Dublin, Ohio, include abrasive grit blasting media for blasting, buffing and polishing applications as well as roofing tile granules and architectural materials (Ref. 11). Seiler has received approval from the California Environmental Protection Agency's Department of Toxic Substance Control (DTSC) for production of recyclable materials from three different waste feed stocks: abrasive blast media, steel mil dust, and industrial waste water treatment sludge (Ref. 12). The reuse of the vitrified product as feed material for the TSV process is also under investigation.

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APPENDIX A

Points of Contact

Project Manager and Principal Investigator

Ashok Kumar
USACERL
2902 Newmark Dr.
P.O. Box 9005
Champaign, IL 61821
Tel: 217-373-7235
a-kumar@cecer.army.mil

Other points of contacts that participated in/knew about the demonstrations:

Robert A. Weber
USACERL
2902 Newmark Dr.
Champaign, IL 61821
Telephone: 217-352-6511 x7239
r-weber@cecer.army.mil

Stephen C. Franks
Quad Cities Resident Office, Louisville District
U.S. Army Corps of Engineers
Rock Island, IL 6120
Telephone: 309-782-1680

Norm Hatcher
Directorate of Public Works
Rock Island Arsenal
Rock Island, IL 61299-5000
Telephone: 309-782-2535

Chester Nakamura
Facilities Department
Marine Corps Base, Hawaii
Kaneohe Bay, HI
Telephone: 808-257-2171

Ken Barnes
Rock Island District
U.S. Army Corps of Engineers
Rock Island, IL 6120-2004
Telephone: 309-794-5439

Contractor:
Tim Troyer
Midwest Foundation Corporation
P.O. Box 1207
Tremont, IL 61568
Telephone: 309-925-2831

Chris Carroll
U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM)
Aberdeen Proving Ground, MD 21010-5422
Telephone: 410-672-5472

Tom Tahada
Naval Facilities Engineering Command
Pacific Division
Pearl Harbor, HI
Telephone: 808-474-5360

Glenn Hirano
Naval Facilities Engineering Command
Pacific Division
Pearl Harbor, HI
Telephone: 808-471-3948

Steven Hobaico
David Taylor Naval Surface Warfare Center
Carderock, MD
Telephone: 301-227 4846

Daniel Zarate
Naval Facilities Engineering Service Center
Port Hueneme, CA
Telephone: 805-982-1057

COL James Kahler
US Air Force Environmental Programs
Hickham AFB, HI
Telephone: 808-449-6953

Ray Travis
Puget Sound Naval Shipyard
Bremerton, WA
Telephone: 360-476-9938

Bryan Akimoto
Directorate of Public Works, Bldg. 1200
Hickam AFB, HI
Telephone: 808-499-2105

Robert Ramm
Puget Sound Naval Shipyard
Bremerton, WA 98314-5001
Telephone: 360-476-2604

Wendell Pollard
Air Combat Command (ACC)
Langley AFB
Newport News, VA 23606-2558

Telephone: (804) 764-2590

Carol Jantzen
Westinghouse Savannah River Co.
Savannah River Technology Center
Aiken, SC 29808
Telephone: 803-725-2374

Louis Rowe
Base Safety Center
Marine Corps Base Hawaii
Telephone: 808-257-1830

Ed Long
Public Works Center
Wheeler Army Air Field, HI
Telephone: 808-656-2878

Thermal Spray Trainer:
Ray Zatorski
Zatorski Coating Company
East Hampton, CT 06424
Telephone: 860-267-9889

Regulator:
John Blazis
Manager Permit Section, Bureau of Air
State of Illinois EPA
Springfield, IL 62794-9276
Telephone: 217-782-2113

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org