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ESTCP COST AND PERFORMANCE REPORT: RC-200610

Application of a Bimetallic Treatment System (BTS) for PCB Removal from Older Structures on DoD Facilities

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF ACRONYMS

ASTM	American Society for Testing and Materials
AMTS	Activated Metal Treatment System
Badger	Badger Army Ammunition Plant
BRAC	Base Realignment and Closure
BTS	Bimetallic Treatment System
CAS	Columbia Analytical Services
CCAFS	Cape Canaveral Air Force Station
Dem/Val	Demonstration/validation (demonstrate/validate)
DoD	Department of Defense
DOT	Department of Transportation
ECAM	Environmental Cost Analysis Methodology
ECD	Electron Capture Detector
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ft	Feet
ft^2	Square feet
GC	Gas Chromatograph
HASP	Health and Safety Plan
ITL	Integrated Transfer Launch
JEGS	Japan Environmental Governing Standard
KSC	Kennedy Space Center
LUT	Launch Umbilical Tower
mg/kg	Milligram per kilogram
mg/L	milligrams per liter
Mg/Pd	Magnesium/Palladium
mL	Milliliters
MS	Mass spectrometry
MSDS	Material safety data sheet
MSFC	Marshall Space Flight Center
NASA	National Aeronautics & Space Administration
NAVFAC	Naval Facilities Engineering Command
NFESC	Naval Facilities Engineering Service Center
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated Biphenyl
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
SAP	Sampling and Analysis Plan

LIST OF ACRONYMS (CONT'D)

SIL	Silicone roof sealant
SRF JRMC	US Naval Ship Repair Facility and Japan Regional Maintenance Center
TA	Treatment Area
TSCA	Toxic Substances Control Act
UCF	University of Central Florida
μg/L	Micrograms per liter
VIB	Vertical Integration Building
VP	Vinyl Polymer

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Executive Summary:

Polychlorinated biphenyls (PCBs) are a group of synthetic aromatic compounds with the general formula $C_{12}H_{10-x}Cl_x$ that were historically used by industry because of their excellent dielectric properties and their resistance to heat and chemical degradation. PCBs were commonly used as additives in paints and asphaltic-based adhesives that were subsequently applied to Department of Defense (DoD) structures. Prior to 1979, PCBs were extensively used in industrial paints, caulking material and adhesives, as their properties enhanced structural integrity, reduced flammability and boosted antifungal properties. Numerous DoD facilities have older metal structures upon which paints containing PCB were applied. These painted structures may present risks to human health or the environment because of inhalation or ingestion concerns as the paint degrades and becomes brittle and can become air-born or impact soil, surface water or groundwater. To date, no reliable methods are available that allow for the removal of PCBs from painted structures/equipment without damaging the coating or the structures/equipment itself.

The overall objective of this project was to refine and deploy a safe, cost-effective, *in situ* treatment method for the removal and destruction of PCBs found on DoD structures. This overall project objective was addressed by the following specific objectives:

1. Determine the protocol for formulating bimetallic treatment system (BTS) for site-specific conditions to enhance applicability to various PCB-containing materials found across numerous DoD facilities while maximizing safety and efficacy with the ultimate goal of reducing PCB concentrations to less than 50 mg/kg.

2. Demonstrate the effectiveness of BTS on a wide range of actual contaminated structures at three DoD facilities. Evaluate the relationships between dose applied, repeated applications and reaction kinetics with the intention of specifically identifying the factors influencing treatment and limiting reaction rates for a specific media (e.g. different painted structures). Evaluate environmental condition effects (temperature and humidity; weathering) and impact of BTS on material appearance and adhesion.

Research and development work at the National Aeronautics and Space Administration Kennedy Space Center NASA-KSC and University of Central Florida (UCF) has led to the development of a bimetallic treatment system (BTS) comprised of elemental magnesium (Mg) coated with a small amount of palladium (Pd) that is utilized in conjunction with a solvent solution capable of donating hydrogen atoms. BTS as a treatment technology has two functions: 1) to extract the PCBs from weathered coating materials and other PCB containing materials such as insulation, rubber gaskets and asphaltic compounds; and 2) to degrade the extracted PCBs. The chemical reductant and catalyst system has been optimized for use in BTS and typically consists of 0.1% Pd on zero-valent or metallic Mg. It is hypothesized that the interaction of the bimetallic Mg/Pd system with a solvent containing available hydrogen moieties (i.e., alcohols) results in the

generation of atomic hydrogen at particular sites on the metal surface. The bound atomic hydrogen is available for reaction with PCB molecules in solution yielding a reductive dehalogenation reaction.

The BTS technology demonstrations were conducted at two DoD facilities: 1) the Vertical Integration Building (VIB) at the Cape Canaveral Air Force Station (CCAFS), Florida; and 2) the Badger Army Ammunition Plant (Badger), Sauk County, Wisconsin. Primary and secondary performance objectives were developed that were evaluated using either qualitative or quantitative performance criteria to determine success. These performance criteria included:

Distribution and Adherence of the BTS One of the qualitative performance objectives is that the BTS applicator is able to evenly distribute the paste on the surface to be treated. The metric was evaluated by assessing the adherence of the BTS to an object in a 0.25 to 0.5 inch layer over the time period of exposure to treated surfaces. BTS was applied using a spray applicator and hand trowel application method. This objective was met although the spray application did not work well in the cold weather implementation.

Adherence of Sealants The metric was evaluated by assessing the adherence of the sealant to the BTS, the ability to apply the sealant evenly over the surface of the paste, and its ability to dry to a non-tacky, non-porous layer that reduced volatilization of BTS solvent. Two sealants were tested: 1) a vinyl polymer (VP) truck bed liner; and 2) a silicone-based roof sealant (Sil). This objective was met using both sealants.

Ease of implementation The ease of use of this technology was evaluated based on our experience in the field. This objective was met with respect to both the ease of handling and applying both the paste and sealant on the various surfaces and locations that were treated.

Reduction in PCB concentrations in treated paint to less than 50 mg/kg A key performance objective is the reduction of PCB concentrations in the treated material to less than 50 mg/kg. This objective was partially met. One application of paste was effective in achieving this target after only one week of treatment in all cases where the starting concentration in the paint was less than approximately 500 mg/kg, especially if the surface being treated was metal and not concrete. In cases where the starting concentrations in the paint were greater than 500 mg/kg, significant reductions (93%) in PCB concentrations were achieved but more than one application of paste is necessary to reduce concentrations below 50 mg/kg.

Reduction in PCB concentrations in BTS paste to less than 50 mg/kg The reduction of PCB concentrations in the paste to less than 50 mg/kg is another key performance objective. This objective was partially met. For the active paste (metal in the paste) if the starting paint concentrations were below roughly 2,500 mg/kg then the concentrations in the paste were less than 50 mg/kg. If the pre-treatment paint concentrations were very high (>20,000 mg/kg) then the active metal paste was not able to degrade all of the PCBs in the paste to below 50 mg/kg although degradation did occur in the paste. Even when Mg/Pd and additional ethanol was added in the laboratory to the active paste that had been exposed to the very high starting concentrations it was not possible to get the concentrations in the paste to below 50 mg/kg after 21 days. For the non-metal paste, which was activated in the lab after removal from the field by the addition of ethanol and the active metal (Mg and acid or Mg/Pd), the concentrations were reduced to below 50 mg/kg for all samples using the acidified ethanol and Mg and/or ethanol and the Mg/Pd.

Follow-on work

Studies conducted at UCF after the project was initiated have shown that the Pd catalyst can be removed from the BTS paste and a small amount of acid added to make a paste that is both less expensive and more reactive. The addition of a small amount of acetic acid to the ethanol significantly increased the rate of PCB degradation. These studies also showed that acidified ethanol with Mg particles was as effective or in some cases more effective than the Mg/Pd particles in non-acidified ethanol at degrading PCBs.

1 INTRODUCTION

1.1 Background

Polychlorinated biphenyls (PCBs) are a group of synthetic aromatic compounds with the general formula $C_{12}H_{10-x}Cl_x$ that were historically used by industry because of their excellent dielectric properties and their resistance to heat and chemical degradation. Although the United States Environmental Protection Agency (EPA) has banned the manufacture of PCBs since 1979, they have been found in at least 500 of the 1,598 National Priorities List (Superfund) sites identified by the EPA. Prior to the EPA's ban on PCB production, PCBs were commonly used as additives in paints and asphaltic-based adhesives that were subsequently applied to Department of Defense (DoD) structures. Prior to 1979, PCBs were extensively used in industrial paints, caulking material and adhesives, as their properties enhanced structural integrity, reduced flammability and boosted antifungal properties. Numerous DoD facilities have older metal structures upon which paints containing PCB were applied. To date, no reliable methods are available that allow for the removal of PCBs from painted structures/equipment without damaging the coating or the structures/equipment itself.

In 2004, National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) began investigating the potential of using a solvent-based system to remove PCBs found in paints located on a number of structures at three of their operating Centers. This innovative research was initially funded by NASA's Environmental Program Office and NASA's Office of Space Flight. The funding included the preliminary proof of concept laboratory research and the demonstration of a Bimetallic Treatment System (BTS) on parts set aside from NASA's Launch Umbilical Tower at KSC.

This project seeks to demonstrate the application of a BTS to remove and degrade PCBs found on structures and equipment at DoD facilities. The project involved the collection of PCB-containing materials from various DoD structures, followed by the laboratory evaluation of the PCB removal efficiency by BTS for each location. This included determining the number of BTS applications required to reach pre-determined cleanup goals stipulated by the various installations. The work then proceed into the field where the BTS was applied to PCB-containing structures at the Vertical Integration Building (VIB) at the Cape Canaveral Air Force Station, FL and the Badger Army Ammunition Plant (Badger), Sauk County, Wisconsin. Both sites had PCBs identified in the paint on the structures and equipment, appropriate site conditions and a suitable on-site support network for execution of the Dem/Val.

1.2 Objectives of the Demonstration

The overall objective of this project was to refine and deploy a safe, cost-effective, *in situ* treatment method for the removal and destruction of PCBs found on DoD structures. This overall project objective was addressed by the following specific objectives:

1. Determine the protocol for formulating BTS for site-specific conditions to enhance applicability to various PCB-containing materials found across numerous DoD facilities while maximizing safety and efficacy with the ultimate goal of reducing PCB concentrations to less than 50 mg/kg. This objective was met.

2. Demonstrate the effectiveness of BTS on a wide range of actual contaminated structures at three DoD facilities. Evaluate the relationships between dose applied, repeated applications and reaction kinetics with the intention of specifically identifying the factors influencing treatment and limiting reaction rates for a specific media (e.g. different painted structures). Evaluate environmental condition effects (temperature and humidity; weathering) and impact of BTS on material appearance and adhesion. This objective was met at the two facilities where testing was conducted.

3. Review BTS application and handling process and develop appropriate on-site safety protocols for institutions to implement during its application, including the handling of any site-specific waste products generated by BTS and the application process. The BTS process itself produces non-toxic waste. This objective was met and this information is included in the project reports.

4. Develop full-scale cost and performance reports for DoD facility end-users to utilize when addressing PCBs found on existing structures. These reports have been prepared.

1.3 Regulatory Drivers

Although the EPA has banned the manufacture of PCBs since 1979, they have been found in at least 500 of the 1,598 National Priorities List (Superfund) sites identified by the EPA. Prior to the EPA’s ban on PCB production, PCBs were commonly used as additives in paints and asphaltic-based adhesives that were subsequently applied to DoD structures. DoD facilities constructed as early as 1930 utilized PCB-containing binders or PCB-containing paints, which are now leaching into the environment and posing ecological and worker health concerns. During the 1950 to 1960 time frame, PCBs were added to paint formulations as drying oils and plasticizers or softening agents in concentrations that range from 10–12% PCBs (100,000–120,000 mg/kg) to 20–30% PCBs (200,000–300,000 mg/kg). Data provided to EPA indicate that PCBs have been found in dried paint at concentrations that range from <1 mg/kg to 97,000 mg/kg (EPA 1999).

In order to dispose of materials containing PCBs in a non-hazardous waste landfill the concentrations must be below 50 mg/kg as per the requirements of TSCA. Disposal of materials containing >50 mg/kg of PCBs in a hazardous waste landfill is expensive and also has the additional and potentially expensive complication of the long-term liability of those wastes. In order for the materials to be recycled and/or reused, which is a preferable option to landfilling from an environmental and economic standpoint, elevated concentrations of PCBs must be reduced in order to allow the materials be handled safely. For instance, scrap metal recovery ovens operating in conformance with 40 CFR 761.72(a) could be used for structures containing PCB concentrations greater than 500 mg/kg. However, the ovens are typically very small, and structures would have to be cut into small sections and a special permit for cutting the structures would be required due to the potential environmental and human exposure risks.

There are few viable options, other than the use of the BTS technology, for removing and degrading PCBs from structures and equipment with coatings such as paint and adhesives utilizing an *in situ* approach. With BTS, PCBs are removed from the structure within hours and are degraded on site to benign end-products. There are no future environmental liabilities associated with off-site disposal and no potential loss of PCB-containing materials to the environment during the removal or treatment process.

2 TECHNOLOGY DESCRIPTION

The following sections provide: an overview of the technology (Section 2.1); technology development (Section 2.2); and advantages and limitations of the technology (Section 2.3).

2.1 Technology Overview

Research and development work at NASA-KSC and UCF has led to the development of a BTS comprised of elemental magnesium (Mg) coated with a small amount of palladium (Pd) that is utilized in conjunction with a solvent solution capable of donating hydrogen atoms. BTS as a treatment technology has two functions: 1) to extract the PCBs from weathered coating materials and other PCB containing materials such as insulation, rubber gaskets and asphaltic compounds; and 2) to degrade the extracted PCBs (Figure 2-1). BTS can be used in a one step process with the paste, including the active metal reductant, being applied to the surface of the material to be treated. The PCBs are extracted from the material being treated by the solvent paste and the PCBs are degraded by the metal reductant within the paste. The BTS can also be use in a two-step process where the solvent paste is applied to the surface to be treated but the paste does not contain the active metal. PCBs are extracted from the material being treated, the paste is removed, and the active metal reductant is added to the paste in a separate container to perform the degradation step. Figure 2-1 is a schematic that shows these two methods.

One Step Process of Extraction and Treatment in Applied Paste

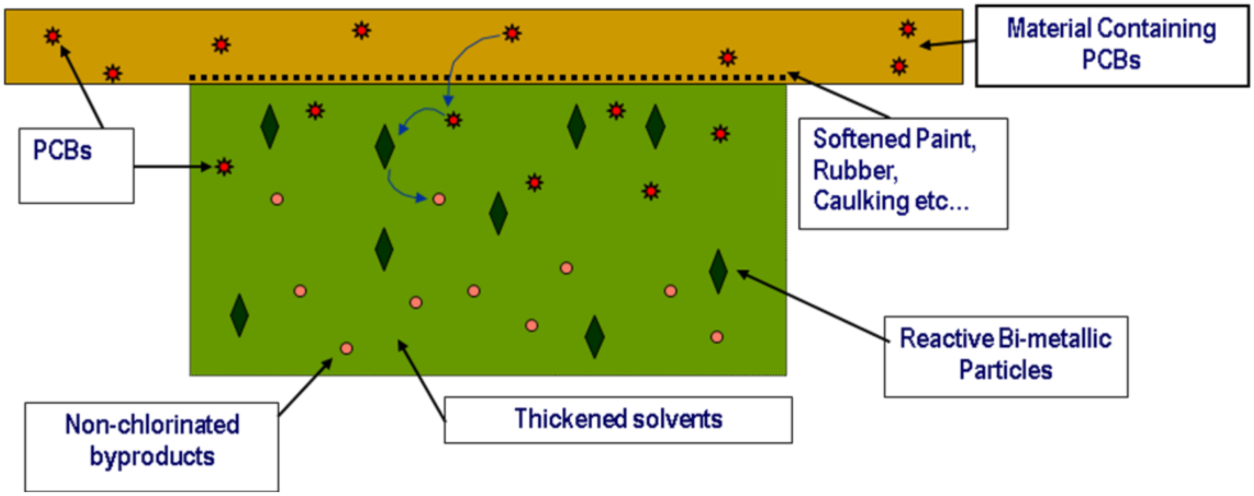


Figure 2-1. Schematic showing the one step process method of applying BTS. The extraction and degradation of the PCBs occurs in this one step using an active (metal-in) paste.

Two Step Process of Extraction of PCBs into Solvent Paste and then Treatment of the Solvent Paste

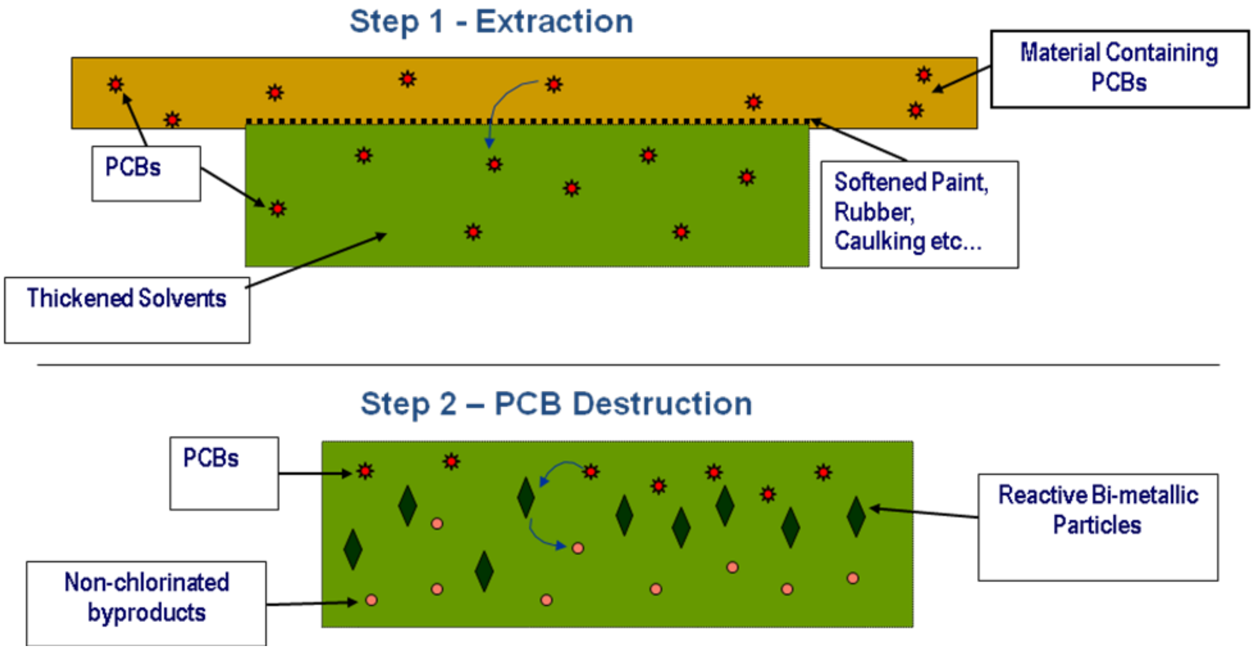


Figure 2-2. Schematic showing the two step process method of applying BTS. In this method the extraction is the first step using an inactive (no metal) paste that extract the PCBs. The paste is then removed and put into a container where reactive metal is mixed into the inactive paste and the degradation step proceeds.

The process for removing PCBs from any type material is accomplished as an independent step to the degradation process. With painted material, the goal is to remove the PCBs from the paint without destroying the paint and collect the PCBs in an environmentally friendly solvent. For some materials being treated, the removal of PCBs may cause a degradation of the materials (e.g., loss of flexibility in caulking materials) making reuse of the material difficult. PCBs are extremely hydrophobic (organophilic) and will partition strongly into the BTS from hardened paint or binder material. The solvent assists in opening, but not destroying, the paint’s polymeric lattice structure, allowing pathways for PCB movement out of the paint and partition into the solvent.

The Mg/Pd bimetallic reductant and catalyst system is a potent dechlorination reagent capable of removing the chlorine from high concentration solution of chlorocarbons in minutes (Engelmann, 2003). It is hypothesized that the interaction of the bimetallic Mg/Pd system with a solvent containing available hydrogen moieties (i.e., alcohols) results in the generation of atomic hydrogen at particular sites on the metal surface. The bound atomic hydrogen is available for reaction with PCB molecules in solution yielding a reductive dehalogenation reaction.

2.2 Technology Development

In 2004, NASA KSC began investigating the potential of using a solvent-based system to remove PCBs found in paints on a number of structures at three of their operating Centers. This innovative research was initially funded by NASA's Environmental Program Office and NASA's Office of Space Flight. The funding included preliminary proof of concept laboratory research and the demonstration of a bimetallic treatment system (BTS) on painted parts containing PCBs set aside from NASA's Launch Umbilical Tower (LUT) at KSC. Data indicated that significant if not complete PCB extraction and degradation from paint chips containing as high as 11,000 mg/kg total PCBs could be achieved with as little as 48 hours of exposure.

The original BTS formulation developed by NASA-KSC and UCF was intended for application to structures that were dismantled and could be treated by immersion of parts of the structures into a liquid treatment bath. In order to treat structures that were not scheduled to be demolished, a treatment system capable of being 'painted-on and wiped off' was needed. In response to this need, further formulation work was conducted in 2004/2005 and an improved formulation of BTS was developed and tested in the laboratory at Marshall Space Flight Center (MSFC) in Huntsville, AL using LUT components. This formulation used a thickened paste BTS system rather than a liquid emulsion-based system to allow the BTS paste to be applied directly to structures in their original location. The data from testing of BTS paste suggests that for painted structures, the paste: 1) is an easier and safer form of BTS to manufacture; 2) can be 'painted-on and wiped-off'; and 3) is effective in removing PCBs from the coating material. Further details in the development of BTS prior to this project are provided in the Demonstration Plans (SI-0610 January and February 2009).

The technology was further developed with the ESTCP funding for this project. A BTS formulation that can be effectively applied using either a paint sprayer or hand application (trowel) and then sealed with either a vinyl polymer or silicone sealant was developed. The BTS was applied to a variety of painted materials (concrete, metal sheeting, metal tanks and machine parts) with a large range in PCB concentrations. The BTS application and handling process was developed with appropriate on-site safety protocols for institutions to implement during its application. Full-scale costs and performance reports were developed for DoD facility end-users to utilize when addressing PCBs found on existing structures. Further details on the development of the technology are provided in the Final technical Report (RC-0610 November 2010).

2.3 Advantages and Limitations

A number of options can be considered for disposal of structures containing PCB-laden materials (such as paints). The following is a list of alternative remediation or disposal options that may be considered for PCB impacted structures:

1. Non-Hazardous State-Approved Landfill (performance-based disposal) where PCB concentrations must be less than 50 mg/kg.

2. Hazardous Waste Landfills (performance-based disposal) can accept material with higher concentrations of PCBs but the costs for disposal of material at hazardous waste landfills can be very high and this option may be cost-prohibitive for large structures. This option does not eliminate the long-term environmental liability associated with the material.

3. Smelters (performance-based disposal, decontamination provisions) Metal may be recovered by recycling that material at metal smelters. The concentrations of PCBs on structures to be smelted must be less than 500 mg/kg. If the structures must be cut into manageable sizes, a special permit is required to perform the cutting operations.

5. Scrap Metal Recovery Ovens (decontamination provisions) Metal may also be recovered by recycling at Scrap Metal Recovery Ovens. This option can be used for material containing PCB concentrations greater than 500 mg/kg, however, the ovens are typically very small, and structures would have to be cut into extremely small sections. A special permit for cutting the structures would be required.

6. Physical Removal of Paint – paint containing PCBs can be removed from surfaces using approaches such as: 1) sandblasting; 2) water blasting; or 3) chemical paint removers and physical scraping. Sandblasting and water blasting may be difficult to control in the open and could result in the release of PCBs into the air or onto surrounding natural media. Chemical paint removers typically contain hazardous chemicals. All these options still require disposal of the PCB-laden material removed from the surfaces. If the PCBs have migrated into the surface in contact with the paint (concrete) then the surface must be scarified to remove the impacted building material.

The BTS technology that was tested in study provides an effective process to remove PCBs from structures and degrade them without transportation to another location. The main advantages of the BTS technology over other treatment technologies include:

- potential for lower overall costs than alternative approaches in some situations;

- elimination of long-term liabilities because PCBs are destroyed rather than being transferred to another medium;

- ability to destroy PCBs on-site without the need to transport the PCB containing material from the site; and

- ability to treat PCBs without needing to destroy the building or structure so that the option exists for reuse of the building or structure.

The main limitations of using the BTS technology are:

- It may be difficult to effectively and quickly distribute the viscous BTS to all surfaces impacted with PCBs especially if they are on irregular surfaces (machine parts, painted pipes running along walls or ceilings). If applying BTS in cold temperature where the paste is more viscous it may not be possible to apply BTS using a spray application and will need to be applied using a trowel.

- The application of BTS to paints and binder materials containing PCBs does have the potential to alter the adhesive qualities of the material while removing and degrading the PCBs. It may not always be possible to leave paints in place and have them function as an effective coating material. Paints, caulking materials or binders containing PCBs, may require reapplication of a new coating after the application of BTS.

3 PERFORMANCE OBJECTIVES

Primary and secondary performance objectives were developed that were evaluated using either qualitative or quantitative performance criteria to determine success. The performance objectives are provided in Table 3-1. The primary objectives are discussed in detail in sections 3.1 to 3.5 and the secondary objectives are discussed in Section 3.6.

3.1 Distribution and Adherence of the BTS

One of the qualitative performance objectives is that the BTS applicator is able to evenly distribute the paste on the surface to be treated. The metric was evaluated by assessing the adherence of the BTS to an object in a 0.25 to 0.5 inch layer over the time period of exposure to treated surfaces. BTS paste was applied to surfaces to be treated using two types of application methods and its thickness estimated. The paste was visually inspected periodically (every two to 5 days for the first week and then weekly for up to a month) to determine if it was able to adhere to the surfaces (both vertical and horizontal treated surfaces) by inspecting for leaks, sections of paste pulling away from the surface or bubbling up off the surface.

This objective was met. BTS was applied using a spray applicator and hand trowel application method. These results are discussed further in Section 6.1.

3.2 Adherence of Sealants

The BTS, once applied, needs to be sealed for the duration of the treatment. The purpose of the sealant is to keep the ethanol-limonene solvent from evaporating. Evaporation of the solvent must be prevented or at least the rate of evaporation reduced so that the paste remains moist. PCB removal from the paint as well as degradation stops if the paste dries. It was decided that a sprayable sealant would be the easiest to apply to cover large surface areas and uneven or complicated (multiple folds or layers such as pipes, pieces of equipment etc…) surfaces.

The metric was evaluated by assessing the adherence of the sealant to the BTS, the ability to apply the sealant evenly over the surface of the paste, and its ability to dry to a non-tacky, non-porous layer that reduced volatilization of BTS solvent. Two sealants were tested: 1) a vinyl polymer (VP) truck bed liner; and 2) a silicone-based roof sealant (Sil).

This objective was met using both sealants. Both sealants were able to provide an effective seal to minimize ethanol evaporation from the BTS paste for the three weeks of application. These results are discussed further in Section 6.2.

TABLE 3-1
PERFORMANCE OBJECTIVES

Performance Objective	Performance Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
Ease and versatility of application of BTS	Adhering to object in a 0.25 to 0.50 inch layer	Measuring layer thickness with a calibrated probe and visual imspection of adherence	Ability to apply BTS to different shaped surfaces using different application technique and have it adhere evenly	Criteria met - (see Section 6.1 for details).
Ability to seal BTS after application	Adhering to BTS and dries to a non-tacky, non-porous layer	Samples will be taken every week and or visual and manual inspections conducted to verify BTS solvent content of paste (See Table 3-24 for analytical methods)	Ability to apply surface coating over BTS such that volatilization is minimized	Criteria met - (see Section 6.2 for details).
Paint adherence post BTS application	Impact to paint adherence	Using an ASTM pull-test procedure and visual inspection of paint condition.	BTS will have minimal effect on painted surface. Structure of paint will maintain basic adhesive properties.	Criteria partially met - (see Section 6.3 for details).
Ease of use	Ability of a technician-level individual to use the technology	Feedback from the technicians on usability of the BTS paste and sealant	BTS will be relatively easy to handle and applly in the field with proper operator training	Criteria met - (see Section 6.3 for details).
Quantitative Performance Objectives				
Reduce PCB concentrations in paint	mg/kg PCBs. Remove samples and analyze for PCBs	Pre and post BTS application sampling and analysis (See Table 3-24 for analytical methods)	Reduction in PCB concentrations in treated paint to less than 50 mg/kg in no less than two applications of BTS.	Criteria partially met - dependent on starting PCB concnetrations (see Section 6.4 for details).
Reduce PCB concentrations in paste	mg/kg PCBs. Remove samples and analyze for PCBs	Pre and post BTS application sampling and analysis (See Table 3-24 for analytical methods)	Reduction of PCB levels within BTS to less than 50 mg/kg in no more than 30 days.	Criteria partially met - (see Section 6.5 for details).

3.3 Ease of implementation

The ease of use of this technology was evaluated based on our experience in the field. The implementability was evaluated by the qualitative assessment of the ease with which the operator was trained to handle and apply both the paste and the sealant in the various field situations.

This objective was met with respect to both the ease of handling and applying both the paste and sealant on the various surfaces and locations that were treated. These results are discussed in greater detail in Section 6.3.

3.4 Reduction in PCB concentrations in treated paint to less than 50 mg/kg

A key performance objective is the reduction of PCB concentrations in the treated material to less than 50 mg/kg. The metric was evaluated by collecting samples of the paint pre-BTS application and then weekly for up to a month for analysis of PCB concentrations. This was a destructive analysis and was done on one section of the test area on a weekly basis until all sections had been analyzed.

This objective was partially met. One application of paste was effective in achieving this target after only one week of treatment in all cases where the starting concentration in the paint was less than approximately 500 mg/kg, especially if the surface being treated was metal and not concrete. In cases where the starting concentrations in the paint were greater than 500 mg/kg, significant reductions (93%) in PCB concentrations were achieved but more than one application of paste is necessary to reduce concentrations below 50 mg/kg. These results are discussed further in Section 6.4.

3.5 Reduction in PCB concentrations in BTS paste to less than 50 mg/kg

The reduction of PCB concentrations in the paste to less than 50 mg/kg is another key performance objective. The metric was evaluated by collecting samples of the paste weekly for up to a month for analysis of PCB concentrations. This was a destructive analysis that was done on one section of the test area on a weekly basis until all sections had been analyzed. For BTS that did not contain the activated metals for degradation (non-active paste) a subset of the paste sample was analyzed for PCBs and then the activated metal and, if necessary, additional ethanol, were added to the non-active paste to promote degradation (post-application activated paste). Samples of the post-application activated paste were then analyzed for PCB concentrations.

This objective was partially met. For the active paste (metal in the paste) if the starting paint concentrations were below roughly 2,500 mg/kg then the concentrations in the paste were less than 50 mg/kg with the one exception of where concentrations were still slightly above the 50 mg/kg target. If the pre-treatment paint concentrations were very high (>20,000 mg/kg) then the active metal paste was not able to degrade all of the PCBs in the paste to below 50 mg/kg although degradation did occur in the paste. Even when Mg/Pd and additional ethanol was added in the laboratory to the active paste that had been exposed to the very high starting concentrations it was not possible to get the concentrations in the paste to below 50 mg/kg after 21 days.

For the non-metal paste, which was activated in the lab after removal from the field by the addition of ethanol and the active metal (Mg and acid or Mg/Pd), the concentrations were reduced to below 50 mg/kg for all samples using the acidified ethanol and Mg and/or ethanol and the Mg/Pd. Further discussion on this objective is presented in Section 6.5.

3.6 Impact to paint adherence

One of the secondary objectives was to evaluate the impact to the paint adherence after exposure to BTS. The metric was evaluated by visually assessing the condition of the paint after BTS application as well as by using the field test for pull-off strength of coatings (ASTM D3359-02).

When the paint at the Badger test sites was subjected to the ASTM D3359-02 procedure prior to application of BTS, the paint at all the test sites failed. Thus, the effect of the BTS on the integrity of the painted surfaces at Badger could not be assessed.

There were difficulties in using ASTM D3359-02 at the VIB on post-treatment samples due to preparation of the surface prior to testing and ASTM D4541-02 was also used to evaluate the paint adherence for the VIB panels.

This objective was not met in that the BTS negatively affected the adherence and strength of at least the surface layer of paint. These results are discussed further in Section 6.6.

4 FACILITY/SITE DESCRIPTION

The BTS technology demonstrations were conducted at two DoD facilities: 1) the Vertical Integration Building (VIB) at the Cape Canaveral Air Force Station (CCAFS), Florida; and 2) the Badger Army Ammunition Plant (Badger), Sauk County, Wisconsin. A third demonstration site was evaluated, the ex-USS CHARLES F. ADAMS (hereafter referred to as ADAMS) in Philadelphia, which is part of the Navy Inactive Ships Program. Samples of painted metal, caulking, wire insulation material, and gaskets were collected in February 2007 and indicated that none of the materials tested contained PCBs at high enough concentrations to warrant a demonstration of the BTS technology. Therefore the funds that were to be used to perform the field demonstration at this site were instead used to develop a methodology to apply a variation of BTS to treat PCB-impacted oil from US Naval Ship Repair Facility and Japan Regional Maintenance Center (SRF-JRMC), located in Yokosuka, Japan.

4.1 Vertical Integration Building

The Vertical Integration Building (VIB) was located at the Cape Canaveral Air Force Station (CCAFS), Florida. Facility 70500 (VIB) was built in 1964 and was used in support of the United States Air Force (USAF) Titan Missile Program, which ceased launch operations in 2005. The entire VIB Facility was scheduled to be dismantled in 2007. As part of the dismantlement efforts, conventional and/or explosive demolition approaches were planned for the VIB, an approximately 98,990 square foot steel framed facility with an 18 level high bay extending to a height of over 230 feet. Portions of the paint on the steel in the VIB High Bay area were documented to contain PCBs greater than or equal to 50 mg/kg that were presumably added during manufacture and/or the original construction in 1964. The VIB deactivation included the demolition, recycling, and/or disposal of the entire VIB Facility. As part of the demolition efforts, steel components with PCB paint concentrations in excess of 50 mg/kg were handled as bulk product waste in accordance with EPA TSCA requirements.

The dismantling of the VIB was expedited and started in late May of 2007 due to concerns with building structural integrity in the upcoming hurricane season. Advance notice was provided to the research team to allow for the arrangement of sufficiently large sections of the painted structures to be removed and transported to Hangar S Storage Building #66232 at CCAFS /KSC for testing (approximately 5 miles from the VIB). The building components that were to be treated were from inside the structure and as such had not been exposed to significant weathering due to sun or rain exposure. The components that were treated during the demonstration (large sections of painted I-beams or similar structural sections) were removed from the VIB structure and treated within Hangar S to maintain a similar environmental setting. Care was taken when removing the structural components of the VIB that were tested to insure that no damage was done to the paint on the sections to be tested.

4.2 Badger Army Ammunition Plant

The Badger Army Ammunition Plant (Badger) is located on the eastside of US12, south of Baraboo, and north of Sauk City in Sauk County, Wisconsin. Badger was established in 1942 and operated intermittently over a 55-year period to produce single and double-base propellants for cannon, rocket, and small arms ammunition. Plant operations were terminated in March 1975 and all production facilities and many support functions were placed on standby. In 1997 the Army determined that Badger was no longer necessary for national defense. Future reuse, ownership, and management of the Badger facility depends on the level and extent of explosive decontamination that can be achieved by the U.S. Army. The contamination that needs to be addressed is the removal, by open burning or "flashing", of explosive potential from the buildings that were exposed to open, uncontained explosives. Those explosives include nitrocellulose and nitroglycerine. The explosive potential is due to the residual explosives that fell on floors, collected in concrete pores, settled or condensed onto pipes, beams and equipment during production of ammunition (Plexus Scientific, 2002).

Further investigation into the buildings and equipment that needed treatment indicated the presence of PCBs in the paint on the structures and equipment. The concern with the PCBs is that the open burning will not produce a sufficiently hot enough flame to destroy the PCBs thus release PCBs into the atmosphere and possible leave residual PCBs in the burn residue.

The building components that were treated are from both inside and outside the structures at the site and as such some had not been exposed to significant weathering due to sun or rain exposure and other components were highly weathered. Prior to the Badger facility being selected as one of the BTS test sites, the Army conducted an extensive testing program for the purpose of determining the level and location of heavy metal and PCB contamination. This surveillance program documented that high levels of PCBs were present at several locations at the Badger site. For example, the rocket propellant press house buildings had PCB levels as high as 11,000 mg/kg in the painted surfaces of the concrete structure. Some of the painted pipes and tanks of the nitroglycerine Nitrating and Separator houses had as much as 59,000 mg/kg of PCBs in the paint. The buildings and materials that were treated at Badger are no longer in use and are scheduled for demolition, recycling or disposal.

4.3 Japanese Machine Oil Site, Yokosuka, Japan

A Navy operation located in Yokosuka, Japan has a series of machines for operations in milling and cutting industrial materials. Over the years, oils containing polychlorinated biphenyls (PCBs) have been used for lubrication in these machines and during this time, PCBs have contaminated the interior of the surfaces of the equipment, including seals and gaskets. Attempts have been made to 'clean' the PCBs out of the equipment by replacing the contaminated oil with new (wash oil) oil but a PCB concentration above the regulatory limit (Japanese limit of 0.5

mg/kg) persists even in the new oil. Materials or equipment containing oils or fluids which exceed the maximum PCB concentration of 0.5 mg/kg will not be allowed into the Japanese economy and must be excessed or disposed via the United States economy. Facilities managers are exploring options to treat PCB-containing oils and fluids so excess equipment can be released locally rather than requiring costly shipment to United States jurisdiction.

UCF obtained a limited amount of lubricating oil from several milling and cutting machines owned by the U.S. Navy. The funding from this project was used only to refine the methodology for treating the PCBs in the oil through laboratory testing. There was no field testing component to this portion of the project. The development of the methodology for treatment of PCB-impacted oil was not part of the original project and therefore was not part of the Demonstration Plans. Rather than trying to fit the description of the workplan and results in the structure of the body of this report, the Final Report for Development a Field Deployable Methodology for Safely and Effectively Degrading PCB Contaminated Oils and Machine Shop Equipment Located at the U.S. Navy Shipyard in Yokosuka, Japan is included as Appendix of the Final Technical Report (RC-0610 2010).

5 TEST DESIGN

This section provides the detailed description of the system design and testing conducted during the demonstration.

5.1 Conceptual Experimental Design

For this demonstration a set of baseline samples were collected from the demonstration sites to evaluate which materials contained PCBs and at what concentrations. Samples were collected of the PCB-impacted materials (painted metal, concrete, and wood) and taken back to the laboratory to test the BTS formulation and sealant options. Once laboratory testing was complete, the field demonstration was conducted. Pre-treatment samples were collected and then the BTS was applied to the painted surfaces and sealed. Both active BTS paste (one step process; paste containing metal; see Figure 2-1) and non-active BTS paste (two step process; no active metal in paste; see Figure 2-2) were used and two types of sealant were tested (vinyl polymer truck bed liner and a silicon roof sealant). Over a three week period sections of BTS were then removed and samples of the paint, BTS, sealant and concrete were collected and tested for PCBs.

5.2 Baseline Characterization and Treatability Study Results

5.2.1 Vertical Integration Building

The VIB deactivation included the demolition, recycling, and/or disposal of the entire VIB Facility. As part of the demolition efforts, steel components with PCB paint concentrations in excess of 50 mg/kg were handled as bulk product waste in accordance with EPA TSCA requirements.

The VIB is located approximately 10 miles from the NASA laboratory where the treatability testing was being conducted, so rather than collecting samples for work in the laboratory; the BTS was applied to small sections of the infrastructure at the VIB itself. Samples of paint were collected from the structural components (I-beams) and taken to the NASA laboratory for PCB testing. Samples of the structures to be treated, sections of painted materials, were used to determine the range of PCB concentrations. The BTS was then applied *in situ* on small sections of the painted metal beams to determine the optimal BTS formulation, and the residual PCB concentration after BTS was applied. Details of these experiments are presented in the Final Demonstration Plan (Demonstration Plan 1, V3, February 2009). The conclusions made based on the results of the laboratory treatability study are presented below.

- There is a large variability in the PCB concentrations in paint that is visually the same and collected from similar sections or structural components of the building.

- There were issues working in the building while it was under demolition (lack of power, access restrictions) and the BTS paste in the *in situ* tests was not completely sealed (the VP liner was applied in too thin a layer).

- Despite less than optimal seal, PCBs were extracted from the paints before the paste dried out.

- A series of sealant tests were also conducted in the KSC paint booth testing room, located behind the KSC laboratory. The tests were conducted using the silicone-based roof sealant (Sil) and this material was able to provide an adequate seal and maintain the moisture in the BTS paste for the duration of the test (over a week).

- Tests were conducted on the application of BTS paste using a textured spray apparatus similar to those used for drywall installation. Using this method an even ¼ to ½ inch layer of BTS paste could be applied on a vertical metal surface.

5.2.2 Badger Army Ammunition Plant

In November of 2006, NASA and the UCF team members traveled to Badger to collect samples from previously identified locations of PCB contamination. The purpose of the visit was to take samples of material that could be tested in the laboratory with the BTS treatment system to establish the optimum formulation and conditions for PCB degradation. During the November 2006 visit to Badger, samples were collected from six major PCB contaminated sites. These sites consisted of two press house buildings, 6810-11 and 6810-36; a wooden rest house, building 6815-08; a nitrating house building, 6657-02; a roll house building, 687-20 and various parts collected from presses located in the staging area.

Based upon analysis and treatment of the collected samples as described in the Demonstration Plan (Demonstration Plan 2, V2, February 2009), it was decided that field testing of the BTS technology would be focused on only four locations, press houses 6810-11 and 6810-36, the nitrating tanks in 6657-02, and the press staging area. Details of these experiments are presented in the Final Demonstration Plan (Demonstration Plan 2, V2, February 2009). The following conclusions were made based on the results of the laboratory treatability study.

- PCB concentrations in paint were higher than had been tested previously with the BTS.

- A sprayable sealant was selected because of ease of application and of the many tested; the VP truck bed liner was selected as the best sealant. The Sil was tested at the VIB and therefore not on the Badger samples.

- It was determined that applying BTS on porous surfaces such as wood and concrete that is not completely sealed with paint resulted in the loss of ethanol from the paste into the treated surface. This resulted in a modification of the paste to include an absorbent material, sodium polyacrylate and cellulose pulp, in the paste to hold extra ethanol but maintain the paste consistency.

- All of the previous tests with the BTS paste were conducted at moderate temperatures between 23 to 27 °C. Because the average temperature during the fall, winter, and spring at Badger are much lower than this, it was decided to conduct a series of tests on the Badger samples at lower temperatures. It was determined that the BTS could perform PCB extractions at lower temperatures but that the rate of extraction might be slower.

5.3 Design and Layout of Technology Components

The BTS used in the field was the same as that used in the laboratory treatability tests. The BTS was composed of 95% ethanol and 5% limonene by volume. The mass percentages for the formulations using an active paste are presented in Table 5-1. A maximum of 20 gal of BTS was applied on the structural components from the VIB and 20 gal at Badger. These estimate were based on the results of the treatability testing done (thickness of BTS applied), including a safety factor. The amount of BTS applied is a function of the covering rate, and is not a function of the reaction kinetics, with the exception of needing to apply a second coat if degradation is not complete after approximately 3 weeks.

Table 5-1. BTS ingredients (including %) for active paste

Component	Weight %
Sodium Polyacrylate	3.4
Cellulose Pulp	3.4
Glycerin	14.8
Calcium Stearate	6.8
Polyethylene Glycol 8000	3.4
90% Ethanol - 10% Limonene	58.2
Mg/Pd Metal Powder	10

In preparation for field-scale deployment, the catalyst was manufactured at UCF for inclusion in the BTS active metal paste. The Mg/Pd reductant/catalyst was manufactured using mechanical alloying techniques. There is no commercial vendor currently identified to produce the reductant/catalyst that has been developed; however, there are a number of potential milling vendors that have this capability for future large-scale production. Once the reductant/catalyst had been manufactured the BTS reagent was prepared at KSC for the VIB demonstration. The BTS paste was prepared at UCF and shipped to Badger for application and evaluation by the research team.

Structural components tested were oriented in both vertical and horizontal positions for application testing. BTS was applied using a texture sprayer and manually using a trowel to a minimum thickness of ¼ inch. Both the vinyl polymer and silicone sealants were tested for sealing the BTS paste. For inactive paste, the BTS was removed at the end of three weeks, placed in a pail and shipped to UCF. Once in the lab at UCF the inactive paste was activated in pails by adding Mg/Pd in an ethanol solution. If moisture levels declined significantly, additional solvent was added to the BTS.

The number and location of BTS application area for each test structural sample varied based on the size and shape of the structural samples available for testing, and other site constraints.

5.4 Operational Testing

There were two main operational phases to this technology demonstration: the *in situ* field demonstration and the follow-up laboratory testing for paste optimization. The field application for both sites involved baseline sampling, BTS paste application and performance monitoring at one, two and three weeks after BTS application (one structural component from the VIB site was monitored at four weeks post-BTS application). All components that were to be tested (paint, paste, sealant and concrete) were taken back to the laboratory at UCF for PCB analysis. All of the paste and sealant that was applied at the field sites was removed; no equipment or materials were left at the field sites.

5.5 Sampling Methods

Prior to treatment, pre-demonstration samples of paint were collected from each section that was to be tested. Samples were also collected after one week, two weeks and three weeks of treatment to evaluate the performance. Samples of the paint from each of the components that were tested (painted metal or concrete) were obtained via the cold-scraping method in order to accurately determine the starting concentration levels of PCBs in the paint. In accordance with ASTM E1729-05, paint samples were collected for analysis using the cold-scraping method with a metal chisel or equivalent scraping tool.

Sample bags were attached to the surface with tape below (vertical surfaces) or adjacent to (horizontal surfaces) the section of paint to be sampled. Care was taken to collect all of the paint scrapings in the sample bag which was then sealed and labeled with the date, contents and sampling location. Pre-demonstration sample locations are shown on Figures 5-1 5-2, 5-3, 5-4 and 5-5.

5.5.1 Vertical Integration Building

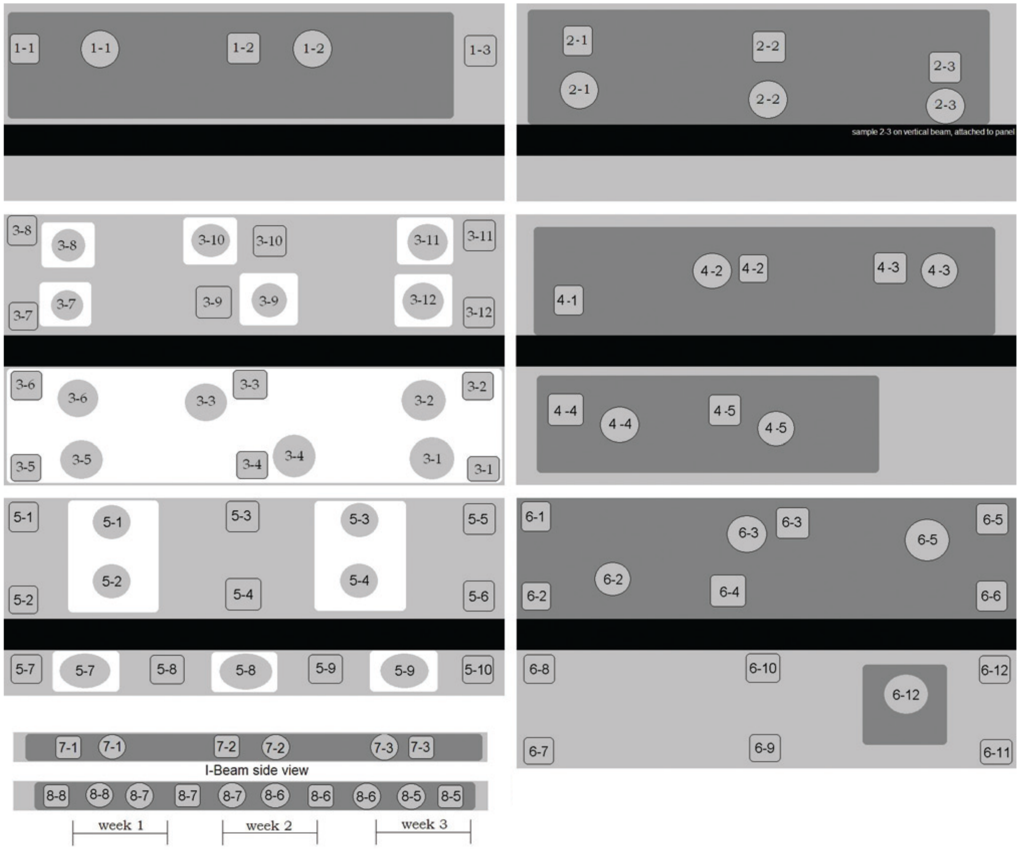
Based on the pre-demonstration laboratory testing that was conducted on paint samples from structural steel components within the VIB and on the painted I-beams themselves within the VIB it was determined that a number of painted surfaces could be used to validate the efficacy of BTS to remove and degrade PCBs. All testing was done on portions of the structural components at least 3 inches from any cut edge or disturbed surfaces to minimize the risk of testing BTS on non-representative materials. A variety of structures and/or surface features (vertical walls, horizontal) were treated. A grid was established on each of the different structural components for an overall treatment area of up to 100 ft^2 to allow for the collection of ten pre-deployment samples and up to thirty post-BTS deployment samples (Figure 5.1). Each square of the grid was large enough to collect both a pre-BTS -deployment sample (Figure 5-6) and up to three post-BTS-deployment samples.

BTS formulations were applied to the type of structural material where known values of PCBs in paint above 50 mg/kg had already been verified using a grid sampling technique described above. Once all pre-deployment samples were acquired, the structural components were coated with BTS using either the spray texture applicator or via manual application (Figure 5-7 and 5-8). The BTS was then sealed with one of two spray sealants to minimize volatilization from the paste (Figure 5-9).

Of the 100 ft^2 area to be treated, 50 percent of the painted surface area was to be subjected to inactive BTS paste and 50 percent treated with active BTS. The BTS application technique ensured that a minimum BTS thickness of ¼ inch is achieved.

The treated structural components were monitored daily for the first week and then weekly for two to three additional weeks for moisture levels and sealant integrity. After one week, two weeks, three weeks, and four weeks, several samples of the paint, the paste and the sealant from within the grid pattern were analyzed for PCB concentration in order to track extraction efficiency from the paint and degradation capability of the paste.

After four weeks at the VIB, all sealant and BTS paste was removed. The inactive paste and its sealant were placed in a drum or pail, shipped back to UCF and the reductant/catalyst and additional ethanol were added to initiate PCB degradation in the recovered inactive paste. The active paste and sealant were subjected to analysis for PCBs in the NASA laboratory.



Legend:

- Numbered rectangles are pre-treatment samples.
- Numbered circles are post-treatment samples.
- Black strips across the panels are the I-beams that separate a panel into 2 sections.
- Light gray areas are the steel panels themselves.
- Dark gray areas on the panels are areas treated with active metal.
- White areas on the panels are areas treated with inactive paste.

Sampling Diagrams for Test Panels 1-6 and Test I-Beam 7-8 BTS Paste Application		Figure **5.1**
Guelph	February 2010	

5.5.2 Badger Army Ammunition Plant

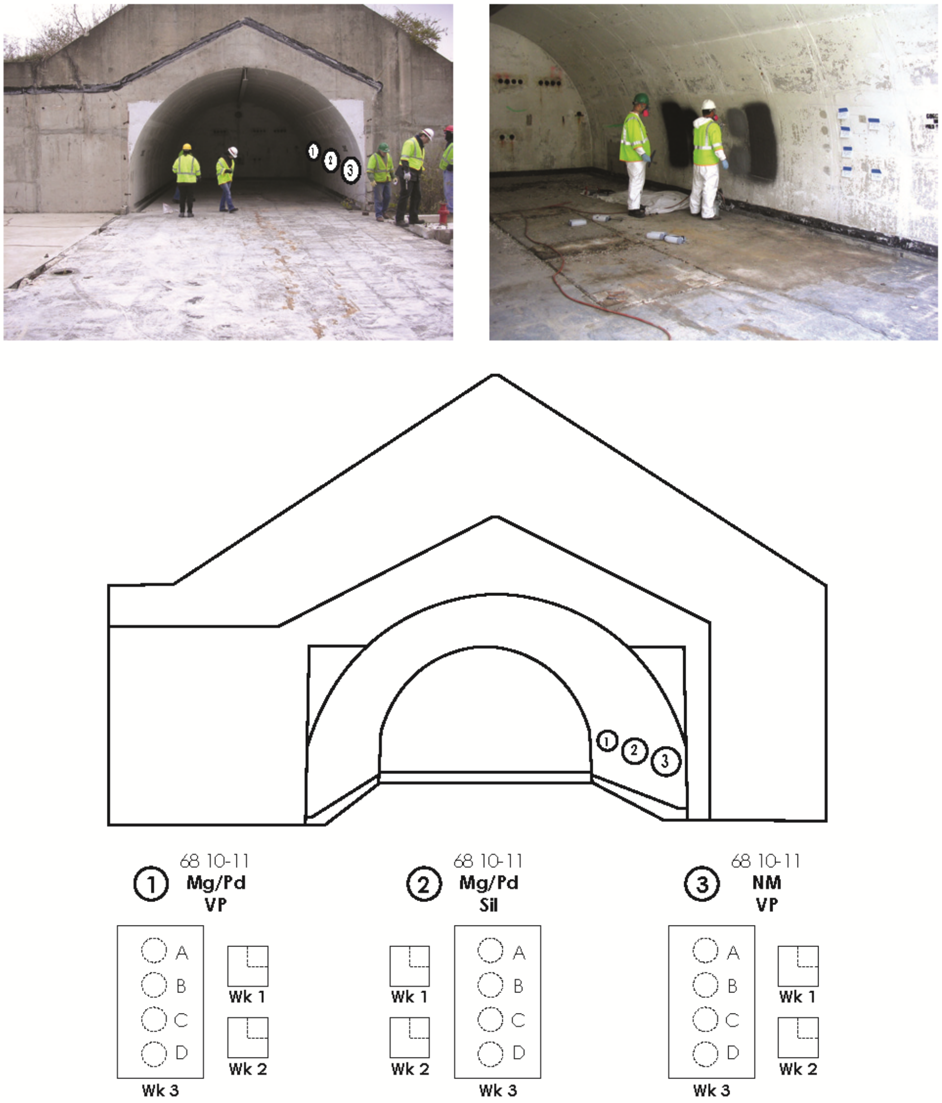
BTS formulations were applied to structural material at the four locations identified in the baseline testing (press houses 6810-11 and 6810-36, the nitrating tanks in 6657-02, and the press staging area; Figure 5.2, Figure 5-3, Figure 5-4 and Figure 5-5, respectively) where known values of PCBs above 50 mg/kg have already been verified using the grid sampling technique described below. Once all pre-deployment samples were acquired, the structural components were coated with BTS using either the spray texture applicator or via manual application.

A grid was established on each of the different structural components for an overall treatment area of up to 100 ft^2 to allow for the collection of pre-deployment samples and post-BTS deployment samples (Figure 5.2, Figure 5-3, Figure 5-4 and Figure 5-5). Each square of the grid was large enough to collect both a pre-BTS -deployment sample and up to three post-BTS-deployment samples. Of the area treated, 1/3 of the painted surface area was subjected to inactive BTS paste sealed with the VP, 1/3 was subjected to active BTS sealed with the VP and 1/3 treated with active BTS sealed with the Sil. The BTS application technique ensured that a minimum BTS thickness of ¼ inch was achieved.

In addition, at Badger, in order to evaluate the potential for the BTS to transfer PCBs from the paint into concrete, samples of concrete were collected prior to BTS application. The paint was scraped off of a roughly 1 in^2 section of concrete where the concrete was to be tested. A sample bag was the taped to the wall below the section to be tested to collect the concrete dust. An electric drill with a concrete drill bit was then used to drill out a section of the concrete to a depth of 3/8-inch. All of the concrete dust from the drill bit was collected in the sample bag which was then sealed and labeled with the date, contents and sampling location. Samples of concrete to a depth of 3/8 inch were taken from each treatment location before and after three weeks of BTS treatment.

The treated structural components were monitored daily for the first week and then weekly for three weeks for moisture levels and sealant integrity. After two weeks, several samples from within the grid pattern were analyzed for PCB concentration in order to track extraction efficiency from the paint. The BTS paste was also analysed for PCB concentration.

After three weeks, all sealant and BTS paste were removed and samples of the paint were taken. The inactive paste and its sealant were placed in a drum or pail, shipped back to UCF and the reductant/catalyst and additional ethanol were added to initiate PCB degradation in the recovered inactive paste. The active paste and sealant were subjected to analysis for PCBs in the UCF laboratory.



Legend

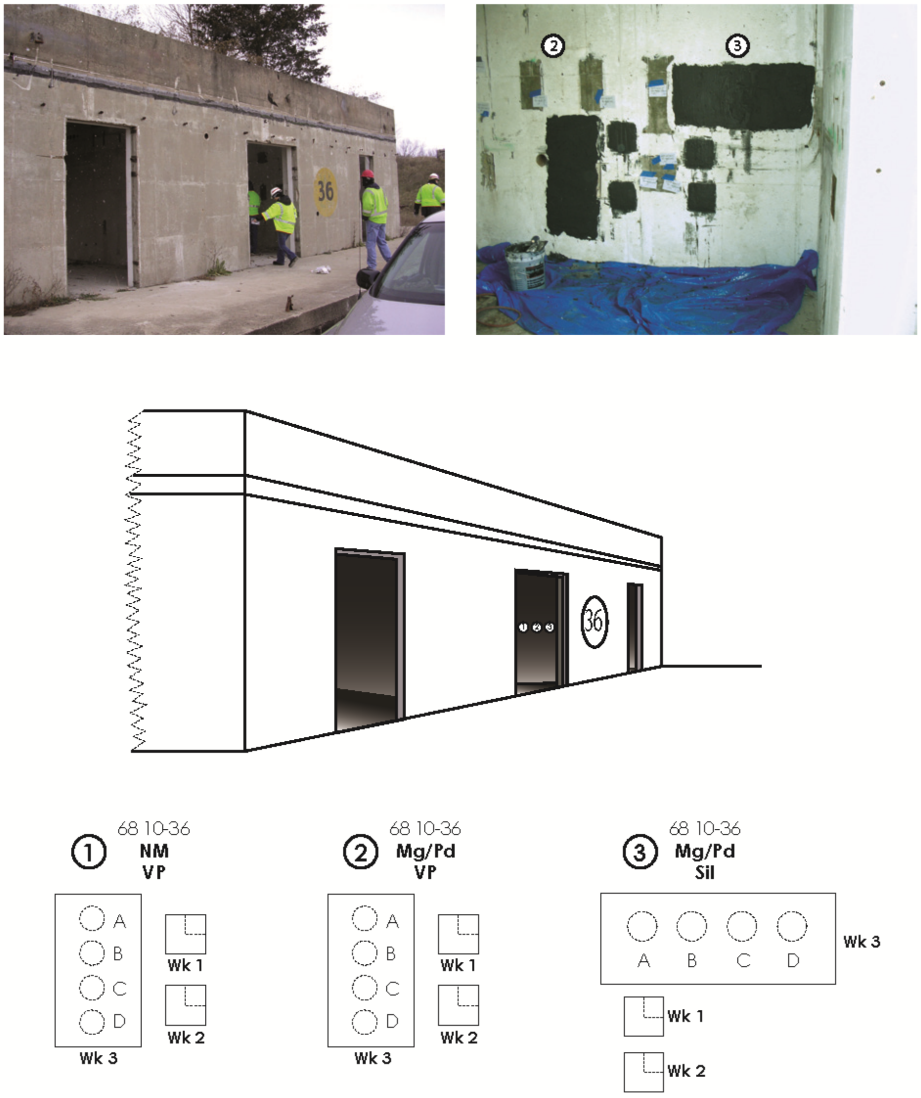
⬚	Indicated pre-demonstration sample location
Wk 1	Week 1 sample area
Wk 2	Week 2 sample area
Wk 3	Week 3 sample area
VP	Vinyl Polymer truck bed liner sealant
Sil	Silicon roof sealant
Mg/Pd	Magnesium Palladium, active paste
NM	No metal, inactive paste

Bunker/Press House 6810-11
BTS Paste Application

Guelph
February 2010

Figure
5.2

5.6



Legend

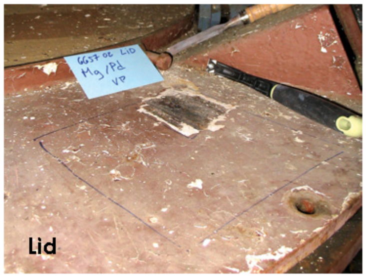
⬚	Indicated pre-demonstration sample location
Wk 1	Week 1 sample area
Wk 2	Week 2 sample area
Wk 3	Week 3 sample area
VP	Vinyl Polymer truck bed liner sealant
Sil	Silicon roof sealant
Mg/Pd	Magnesium Palladium, active paste
NM	No metal, inactive paste

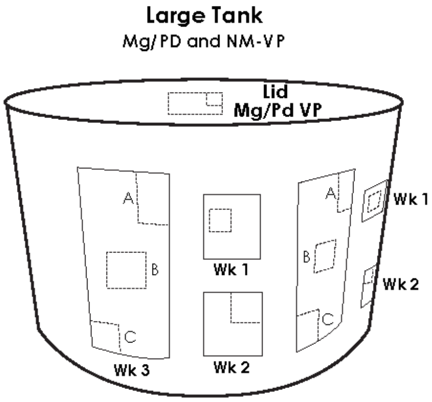
Press Building 36.ai

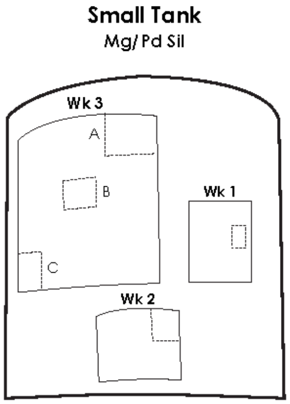
Press Building 6810-36
BTS Paste Application

Guelph
February 2010

Figure
5.3







Legend

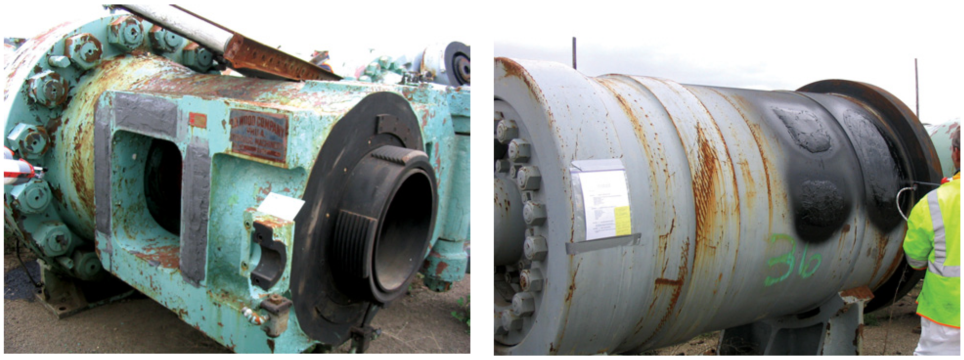
⬚	Indicated pre-demonstration sample location
Wk 1	Week 1 sample area
Wk 2	Week 2 sample area
Wk 3	Week 3 sample area
VP	Vinyl Polymer truck bed liner sealant
Sil	Silicon roof sealant
Mg/Pd	Magnesium Palladium, active paste
NM	No metal, inactive paste

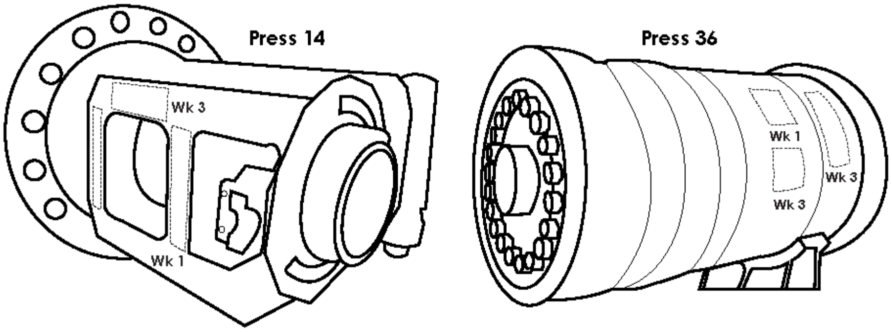
Nitrating House 6657-02
BTS Paste Application

Guelph | February 2010

Figure
5.4

Nitrating House.ai





BTS Paste applied to various spots on press #4, 12, 14, 15, 36

Legend

⬚	Indicated pre-demonstration sample location
Wk 1	Week 1 sample area
Wk 2	Week 2 sample area
Wk 3	Week 3 sample area
VP	Vinyl Polymer truck bed liner sealant
Sil	Silicon roof sealant
Mg/Pd	Magnesium Palladium, active paste
NM	No metal, inactive paste

BTS Paste Applied to Presses BTS Paste Application		Figure **5.5**
Guelph	February 2010	

Staging Area.ai

Analytical Methods

Table 5-3 presents a summary of the analytical methods used in the demonstrations. Information pertaining to calibration of analytical equipment, quality assurance, decontamination and sample documentation can be found in Appendix B and C of the Final Technical Report (RC-0610, 2010).

5.7 Sampling Results

This section provides a summary of all sampling results; Section 5.6.1 provides the results of the adhesion tests; Section 5.6.2 provides the results of the Vertical Integration Building; Section 5.6.2 provides the results of the Badger demonstration; and Section 5.6.3 presents the results of the paste optimization studies. Tables summarizing sampling results can be found in Appendix D of the Final Technical Report (RC-0610).

5.7.1 Adhesion Testing

Qualitative and quantitative analysis of the painted surfaces were performed following the application and removal of BTS from the different test panels at the VIB. Initially, a visual inspection indicated that the paint appeared to remain intact following exposure to BTS, however a closer look showed that the upper coat of paint was softened. This indicated that adhesion/integrity of at least the surface layer of paint was negatively impacted from exposure to the BTS solvent system.

A qualitative method for measuring adhesion of coatings is ASTM D3359-02, in which pressure-sensitive tape is applied and removed from cuts made into the coating surface. This consists of making an X-cut through the film to the substrate, followed by applying pressure-sensitive tape over the cut and removing it. A qualitative assessment of the adhesion is then made by visually inspecting the amount of coating removed by the tape and a score of 0 (complete removal) to 5 (no peeling/removal) is given.

Untreated areas of panel 3 and 4 were tested as a control, to determine the adhesion qualities of the paint prior to BTS exposure. Both panels (untreated) were scored a 5, indicating no peeling or removal of the paint upon removal of the pressure-sensitive tape as expected, since neither sample had been exposed to the paint softening effects of BTS. Treated areas of panels 3, 4, and 5 were tested using this qualitative method. These three samples showed varying amounts of impairment of the adhesion qualities of upper layer of paint. Initial testing seems to indicate a loss of adhesion to samples exposed to BTS.

TABLE 5-3
SUMMARY OF SAMPLE HANDLING AND LABORATORY ANALYTICAL DETAILS

	Parameter	Analytical Method	Method Number	Analytical Laboratory (1)	Quantitation Limit	Sample Container	Preservative	Holding Time
PASTE	PCB and degradation products in paste	Gas Chromatography	EPA 8082	UCF/KSC	0.10 mg/kg	plastic bottle for collection/glass for extraction	none	N/A
	Moisture Content of BTS	Visual Inspection Manual Inpection	N/A	N/A	N/A	N/A	N/A	N/A
PAINT	PCB and degradation products in paint	Gas Chromatography	EPA 8082	UCF/KSC	0.10 mg/kg	plastic bottle for collection/glass for extraction	none	n/a
	Adhesion of paint	Field Test of Pull-Off Strength of Coatings	ASTM - D4541-02	N/A	N/A	N/A	N/A	N/A
SEALANT	Sealant integrity	Visual Inspection	NA	NA	NA	NA	NA	NA
	PCB and degradation products in sealant	Gas Chromatography	EPA 8082	UCF/KSC	0.10 mg/kg	plastic bottle for collection/glass for extraction	none	N/A

Notes:

N/A - Not Applicable

UCF - University of Central Florida

KSC - Kennedy Space Center

(1) - 10% of the samples will be sent to a conmerical laboratory (to be determined) for confirmatory analysis.

TBD - To be determined

Table 5-4. Qualitative analysis of adhesion properties using ASTM D3359-02 for both treated/untreated sample areas.

Panel	Treated	Score
3	Yes	0
4	Yes	5
	No	5
5	Yes	0
	No	5

In several cases, tests were not deemed accurate due to an inability to form sufficient contact between the pressure-sensitive tape and coated surface, leading to a skewing in the results. It was decided that a second test method should be employed o further evaluate the effects of BTS on the adhesion of the paint. A quantitative analysis method of adhesion properties is given in ASTM D4541-02. A loading fixture is affixed to the sample site using an epoxy adhesive. The final values are presented as force (psi) required to remove the loading fixture from the coated material. Qualitative assessments are made to the amount of material affixed to the loading fixture. This data is presented in Table 5-5.

Table 5-5. Quantitative analysis of adhesion properties using ASTM D4541-02 for both treated/untreated sample areas.

Sample ID	Treated (Y/N)	Force (psi)	Comments
3-1a	Y	459.77	
	N	329.15	Overspray from coating may have affected adhesion
3-1b	Y	845.48	Poor coating caused BTS to dry out quickly
4-5a	Y	208.74	
	N	1353.64	
4-5b	Y	157.72	
	N	382.21	Didn't removal all paint, possibly poor adhesion
5-1	N	804.66	
5-7	N	1282.21	
7-1a	Y	196.50	
	N	761.81	
7-1b	N	623.03	

Less force was necessary to remove the loading fixtures after BTS application had occurred compared to the force necessary to remove the fixtures from untreated samples. A few samples didn’t follow this trend, but this was likely due to the sample surface not being properly prepared resulting in an incomplete bonding of the epoxy material used. This is indicative of loss of the adhesive forces between the surface coat and material below the surface. It is interesting to note that in the majority of the tests (both qualitative and quantitative); the loss of adhesion was found to occur primarily between the surface coat and the primer coat. The primer coat itself remained intact after prolonged exposure to BTS, indicating that the majority of structural integrity loss is occurring within the surface coat. It may be that while the surface coat may need reapplication post-exposure to BTS, the primer coat would be suitable for use without removal/replacement.

Qualitative and quantitative analysis of painted surfaces at the various Badger test sites were to be performed following the application and removal of BTS from the test surfaces. Initial visual inspection of the painted surfaces at the four different test sites, two concrete press bunkers, the nitrating house and the staging area, indicated that the paint was in poor condition prior to treatment with BTS. Significant peeling and flaking of the paint was evident at each of the test sites. Figure 5-6 gives a representative view of the quality of the paint in the concrete bunkers.

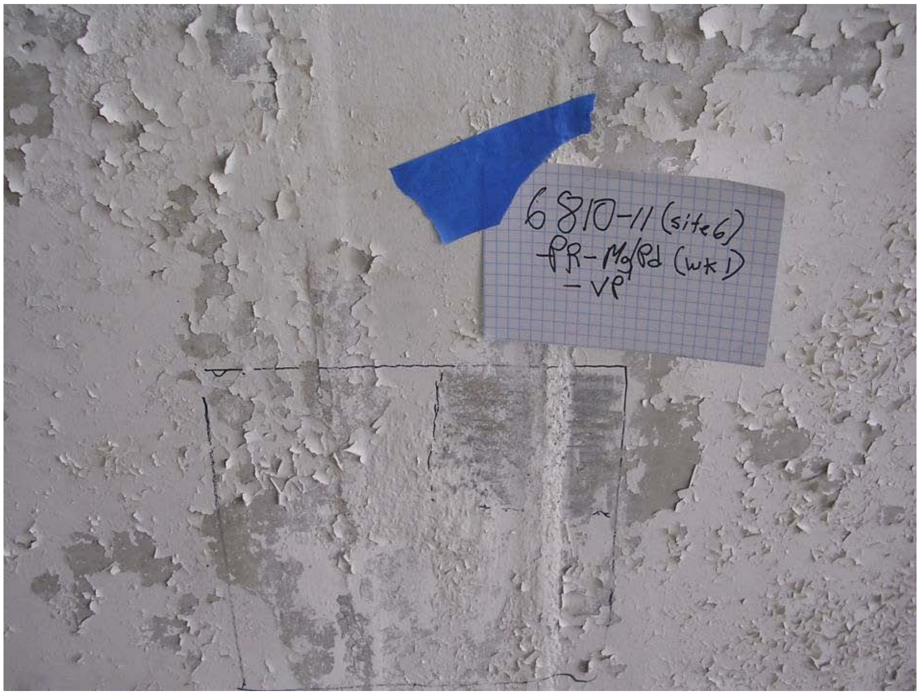


Figure 5-6. Representative quality of the paint in concrete bunker 6810-11.

As with the VIB, ASTM D3359-02 was used to evaluate the adhesion of the paint pre and post-treatment. However, when the paint at the Badger test sites was subjected to this procedure prior to any exposure to BTS, they all failed (all scored 0). Thus, the effect of the BTS on the integrity of the painted surfaces could not be assessed.

5.7.2 Vertical Integration Building

PCB Analyses

Pre Demonstration PCB concentrations in the VIB samples ranged from ~10 to ~100 mg PCB/kg paint and all samples tested were identified as PCB congener mix 1260. The data clearly shows that high levels of removal of PCBs from the paint were achieved with both the active and inactive paste formulations (Figure 5-7). The average removal of PCBs from the paint from the entire test site was nearly 80% with a single application. Several samples were remediated to below PCB detection limits.

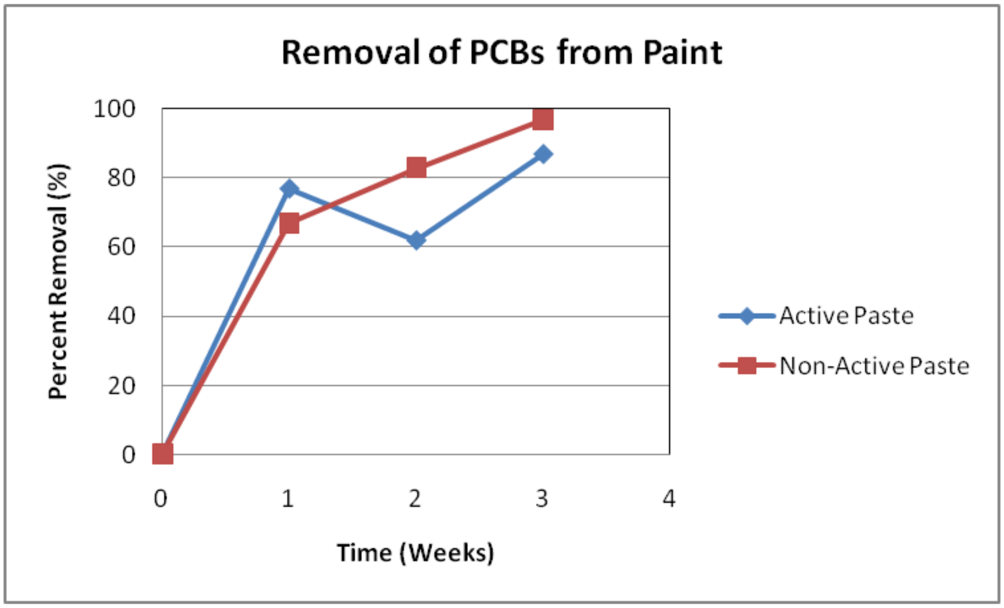


Figure 5-7 PCB in paint concentrations after 1, 2 and 3 weeks of exposure to BTS. Average of samples (2 samples at 1 week and 2 weeks and 10 to 20 samples at week 3)

The loss of PCBs in the paint and the presence of PCBs within the BTS confirm the technology's ability to remove chlorinated contaminants from building materials such as paint to below 50 mg/kg. However, even though we can say BTS efficiently removes PCBs from the paint, it is difficult to make a quantitative analysis of this removal capacity from an examination of the paste, due to the low levels of PCBs originally found in the VIB paint (and consequently in the BTS material). The low levels found within the paste are not surprising, considering the relative volumes of treated paint and BTS used (thin layer of paint, thick layer of paste resulting in dilution of the PCB concentrations). Dechlorination of the original PCB envelope (mixture of PCB congeners) was demonstrated by the formation of the lower chlorinated byproducts and a corresponding PCB envelope shift. Results from the Badger demonstration, where starting concentrations of PCBs in the paint and subsequently in the paste were higher, are presented below in Section 5.7.3.

5.7.3 Badger Army Ammunition Plant

PCB Analyses

The PCB concentrations in the paint located at the different treatment sites at Badger at times of pre-demonstration, and after one, two and three weeks of treatment are shown in Figures 5-8, 5-9, 5-10 and 5-11. As can be seen from the data, the major drop in PCB concentration occurs in the first week. The concentrations of PCBs in the paint do not change significantly between week 1 and week 3.

PCB concentrations in paint in building 6810-11 were between 1,800 mg/kg and 3,880 mg/kg in the pre-demonstration samples. Post-treatment concentrations (1 to 3 weeks of treatment) in paint were between 96 mg/kg and 200 mg/kg. PCB concentrations in paint in building 6810-36 were between ~ 400 mg/kg to as high as ~900 mg/kg prior to treatment. Post treatment concentrations in paint were between 96 mg/kg and 200 mg/kg. In Building 6657-02, PCB concentrations in paint were between 20,000 mg/kg to as high as 33,000 mg/kg prior to treatment. These are the highest PCB concentrations that the BTS paste has ever been tested on. Post treatment concentrations in paint were between 10,000 mg/kg and 16,000 mg/kg. The PCB concentrations in the pre-demonstration paint samples collected from the presses in the staging area were between 10 mg/kg and 160 mg/kg. The PCB concentrations in the paint on the presses are much lower than those that were observed at other test locations on the walls and on the tanks. At all of the sample sites that were treated, the PCB levels were reduced to very low levels, below the regulatory limit of 50 mg/kg after only one week of exposure.

The target of 50 mg/kg in the paint was not achieved with high starting concentrations (>1,500 mg/kg) in the paint because the PCBs extracted into the paste exceeded the degradation capabilities of the Mg/Pd and then the paste became saturated with PCBs. The paste was no longer able to further extract PCBs from the paint. It may require multiple applications to get all concentrations below 50 mg/kg with starting concentrations above 1,500 mg/kg. Also, when the paste was applied to a porous surface such as a concrete wall with poor paint coverage, the amount of ethanol available in the paste was reduced due to some loss of ethanol to the concrete. This can been seen by comparing the similar starting concentrations of PCBs in the painted concrete in building 6810-36 and the painted metal presses but the paste wasn’t able to reduce the concentrations as effectively in the painted concrete. In addition, there were issues with some of the sealant performance at the low temperatures that added to the inability to meet the 50 mg/kg target in the pain. Observations during this demonstration suggest that the low winter temperatures during the demonstration at Badger caused cracking in the sealant and made it difficult to control evaporation of the solvent. It is recommended that future applications not be conducted during cold winter months.

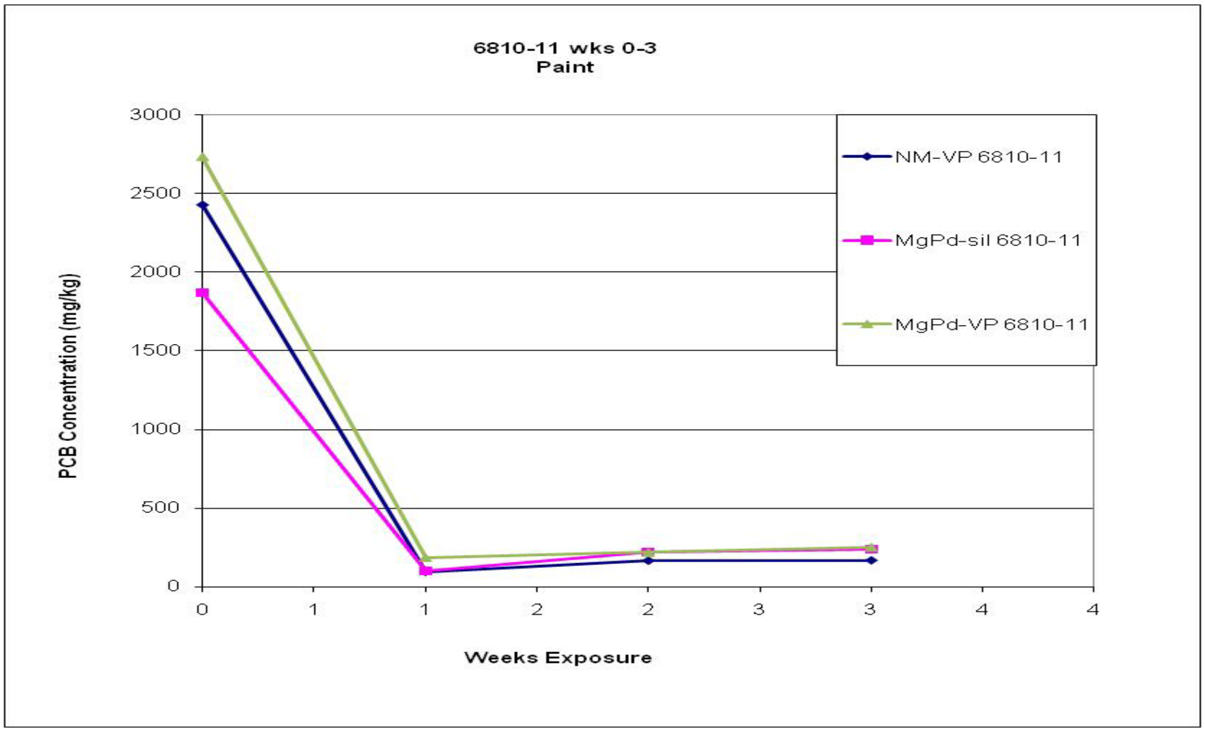


Figure 5-8. Average Concentrations of PCBs in paint during treatment times of 0-3 weeks.

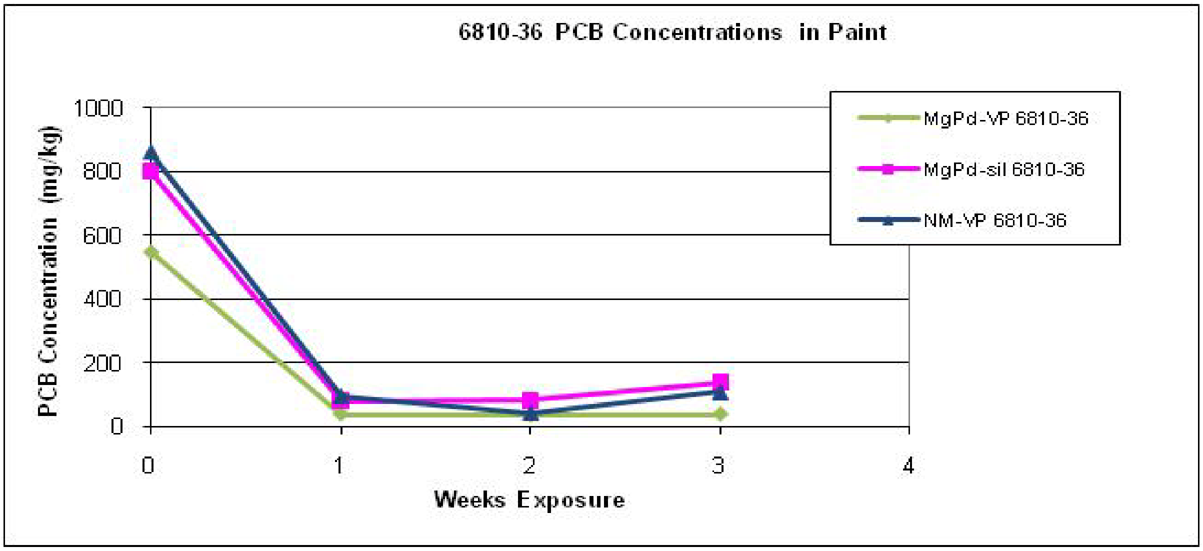


Figure 5-9. Average PCB concentrations in paint samples from 6810-36.

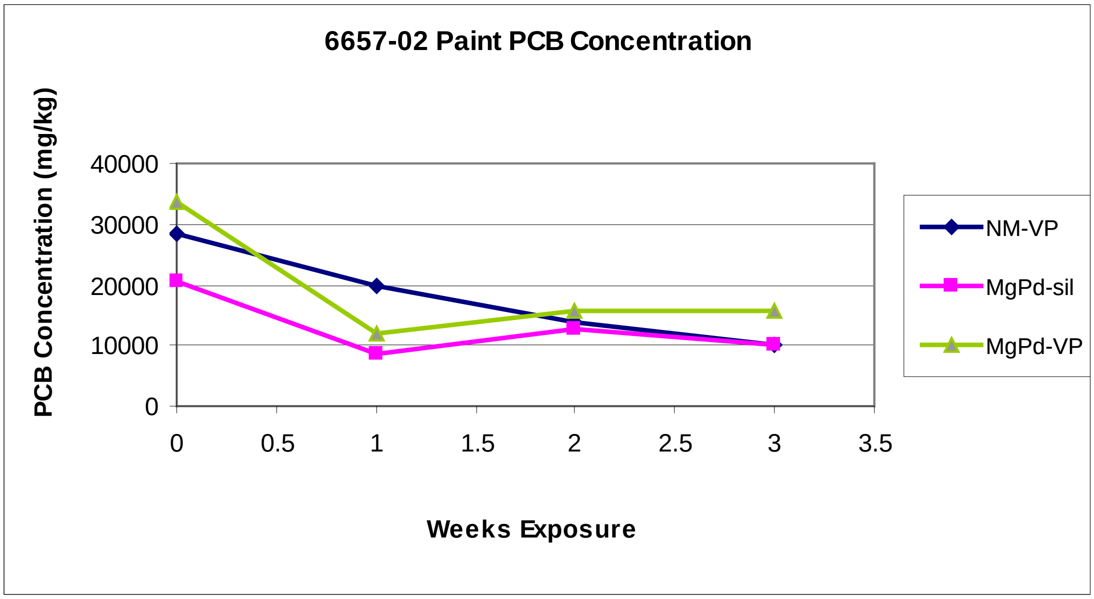


Figure 5-10. Average PCB concentrations in paint samples from 657-02.

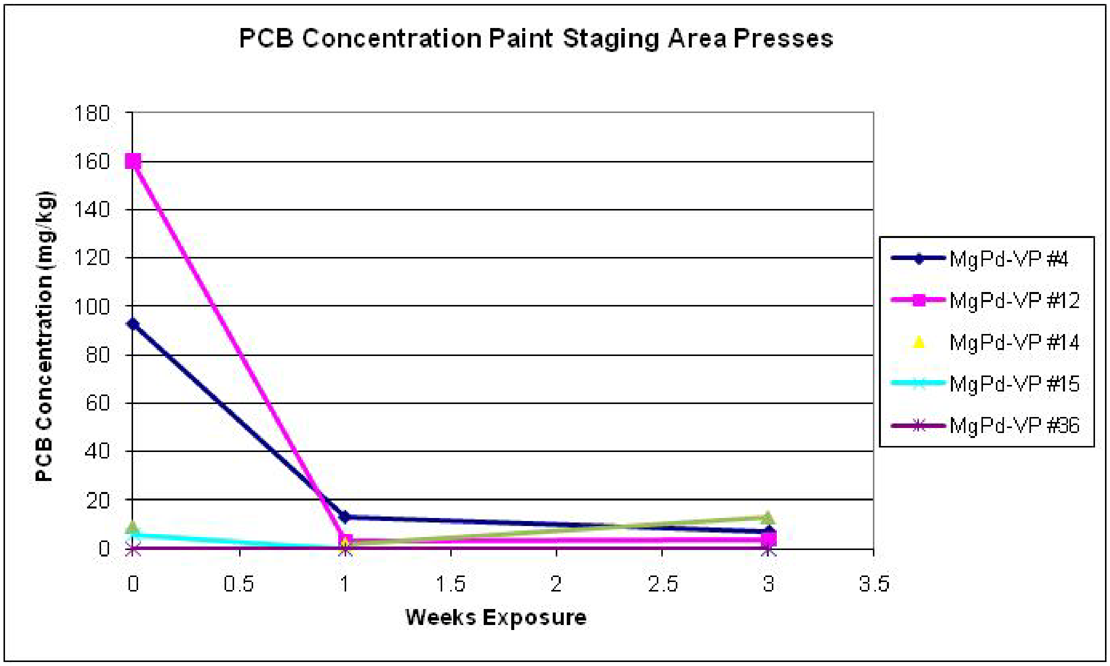


Figure 5-11. Average PCB concentrations in paint samples from various staging area equipment at 0, 1, and three weeks after BTS exposure.

The BTS paste was also analyzed for PCB concentrations after application and removal. Samples of BTS paste were collected from each test location at the same time after treatment that paint samples were collected. The data from these analyses is plotted in Figures 5-12, 5-13, 5-14, and 5-15.

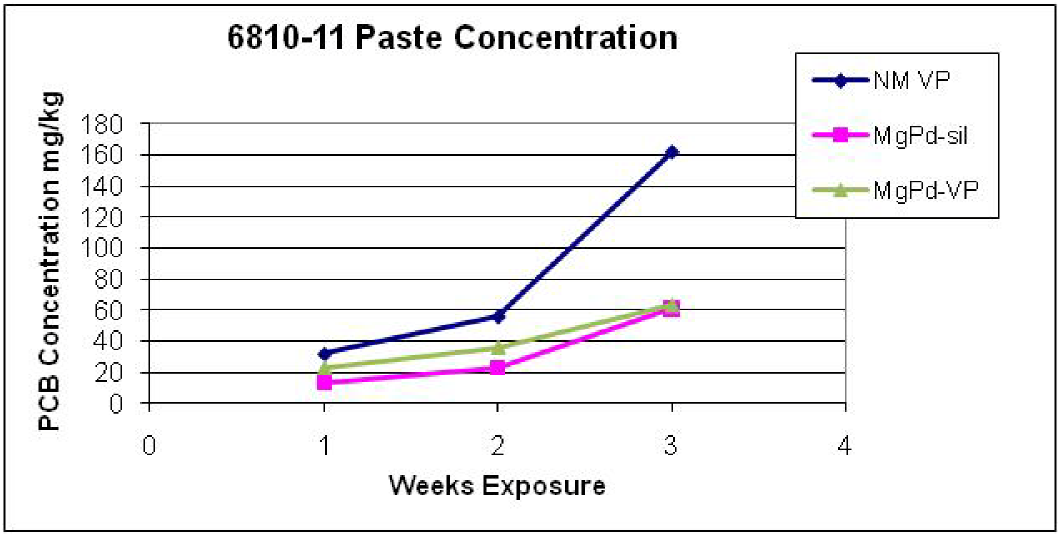


Figure 5-12. Average PCB concentration in paste for weeks one through three.

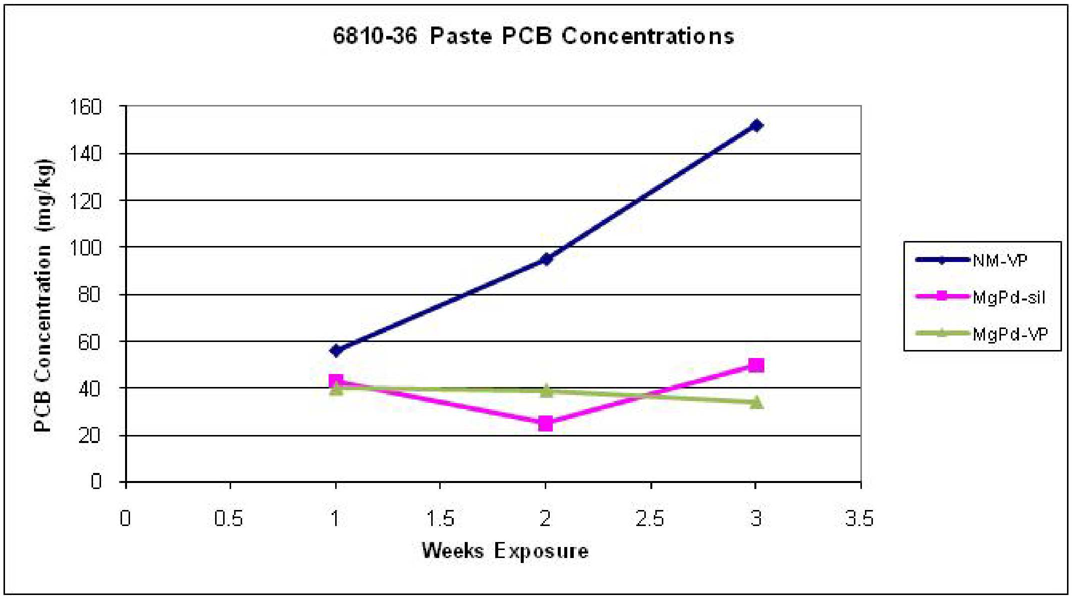


Figure 5-13. Average PCB concentrations in paste sampled at 1-3 weeks after BTS application,

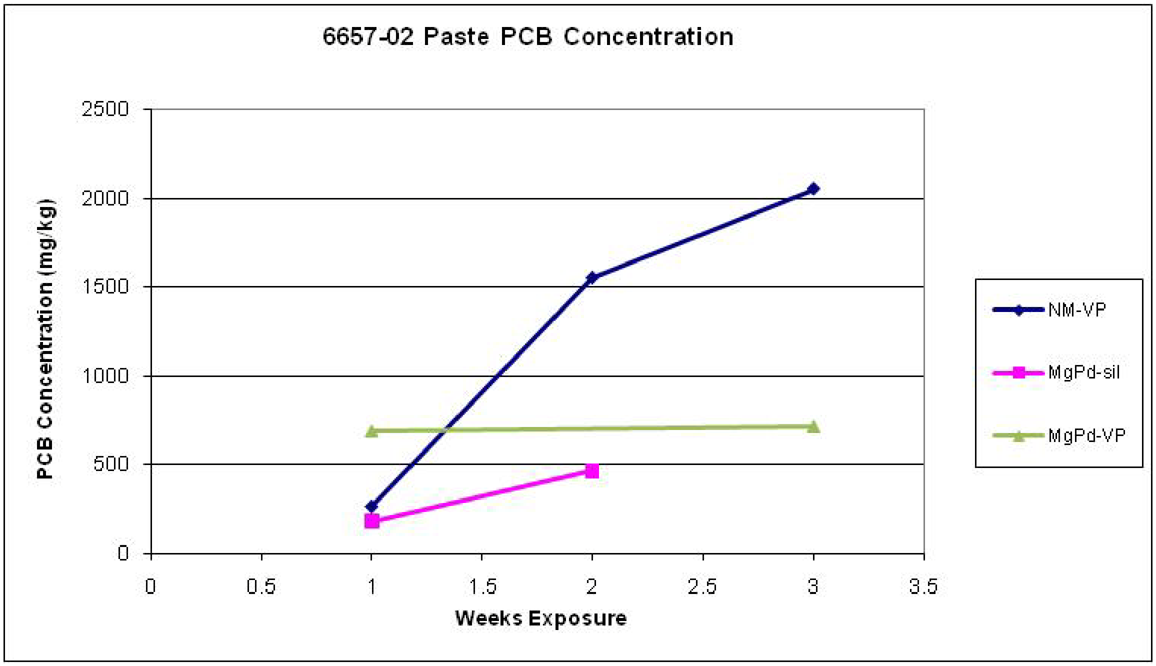


Figure 5-14. Average PCB concentration in pastes from building 6657-02 for weeks 1-3.

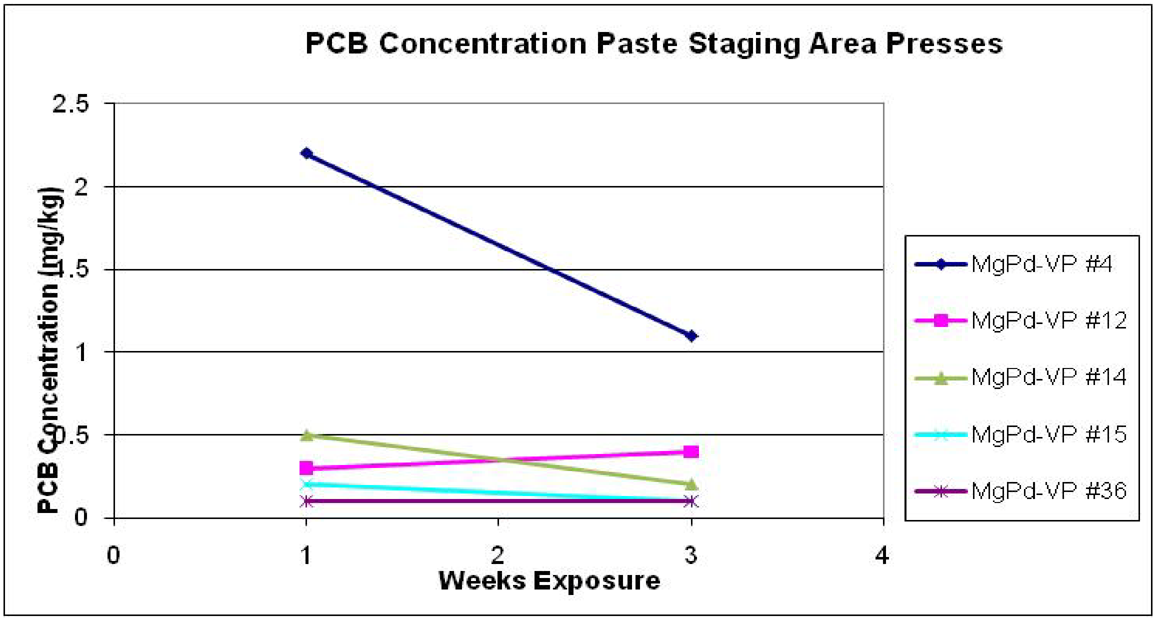


Figure 5-15. PCB concentration in paste from staging area (all presses) for weeks 1 and 3.

The PCB concentrations in the Mg/Pd BTS were lower than the NM paste. This is as expected because the active Mg/Pd particles are continuously degrading PCBs as they enter the paste. The concentrations of the PCBs in the paste are those that were present in the paste soon after the samples were collected and returned to UCF for analysis. The PCB concentration in the paste continued to increase in weeks two and three even though little to no additional PCBs were being removed from the paint. It is believed that there was still some solvent evaporation from the paste over time and after sampling which led to a concentrating effect. Because the PCB concentration in paste is reported on a weight basis, as the solvent in the paste evaporates, the PCB concentration increases.

Samples of concrete were taken prior to treatment and after three weeks of treatment to determine if the BTS paste would transport any PCBs into the concrete. The samples were taken from the surface (after paint removal) to a depth of 3/8 inches into the concrete at several locations in the 6810-11 and 6810-36 test area. The data suggest that BTS paste does not transport PCBs from the paint into the concrete but rather transports PCBs from the concrete into the paste. This property of BTS paste has also been observed and confirmed in laboratory studies.

BUILDING 6810-36 CONCRETE									
Pre-Treatment					Post Treatment				
Sample ID	Active (Y/N)	Conc (mg/kg)	TR AVG	STD DEV	Treatment Time (wks)	Conc (mg/kg)	TR AVG	STD DEV	Average % Removal
MgPd Sil 1wk concrete	Y	85	139	49	1	17	18	3	87%
MgPd Sil 1wk concrete	Y	110			1	16			
MgPd Sil 1wk concrete	Y	183			1	23			
MgPd Sil 1wk concrete	Y	178			1	17			
MgPd VP Concrete	Y	50	59	18	3	10	20	10	66%
MgPd VP Concrete	Y	60			3	37			
MgPd VP Concrete	Y	43			3	16			
MgPd VP Concrete	Y	39			3	15			
MgPd VP Concrete	Y	75			3	28			
MgPd VP Concrete	Y	84			3	14			

Notes:
AVG - four to six samples were taken from the same sample container, extracted separately and analyzed, these numbers are averaged.
mg/kg - milligrams per kilogram
Mg/Pd - magnesium/palladium
SIL - silcone sealant
STD DEV - standard deviation of data set.
TR AVG - treatment average
VP - vinyl polymer sealant

Both the VP and the Sil sealants from the Badger test sites were removed and returned to UCF for analysis. Analysis of the sealant samples showed that there were no detectable PCBs found in any of the sealant.

5.7.4 Paste Optimization Studies

As discussed in previous sections of this report, all of the BTS paste that was used in the Badger field test was returned to UCF for further study. Two types of paste were used in the field test, one contained Mg/Pd particles (Mg/Pd BTS) and the other contained no metal particles (NM BTS). Immediately after the paste samples were returned to UCF, they were analyzed for PCB concentrations. Samples of the paste that contained more than 10 mg/kg of PCBs were chosen for further degradation studies.

The additional degradation studies involved adding ethanol containing 1% acetic acid to the paste to re-wet the Mg/Pd containing paste. Sufficient acidified ethanol was added to make the paste take on a bread dough type of consistency. Ethanol had to be added to the paste because some of the paste had dried out *in situ* before removal from the test site. Some of the paste dried out during the field test because some of the sealant developed cracks allowing the ethanol to evaporate. This is believed to have been caused by the cold weather conditions during the demonstration at Badger. At the test sites where the sealant remained intact, the paste did not dry out during three weeks of exposure. In order for PCB degradation to take place, a proton donor solvent such as ethanol must be present. The reason for adding the acetic acid is that studies conducted at UCF after the Demonstration Plans were submitted showed that the addition of a small amount of acetic acid to the ethanol significantly increased the rate of PCB degradation. These studies also showed that acidified ethanol with Mg particles was as effective or in some cases more effective than the Mg/Pd particles in non-acidified ethanol at degrading PCBs. This discovery is extremely important because it means that Pd is not required in the BTS formulation, which reduces the cost of the BTS paste significantly. Plain acidified Mg particles were not used during the Badger test because the Demonstration Plan called for using BTS with Mg/Pd particles and BTS without any Mg/Pd particles. However, acidified Mg particles were tested on the BTS paste that was returned to UCF from the Badger test site. The data obtained for the PCB degradation performance of the acidified Mg particles are reported in this section along with the data obtained for the Mg/Pd particles.

Treatment of the Badger BTS paste was performed using both Mg/Pd and Mg in conjunction with the use of ethanol containing 1% acetic acid. Only samples from sites 6810-36, 6810-11 and 6657-02 were tested because as shown in the previous section, the PCB concentration in the paste samples taken from the staging area were so low (less than 2 mg/kg) that degradation studies on them would have been of no value. A bar graph showing the change in PCB concentration upon treatment for the samples is shown in Figure 5-16.

Significant PCB degradation was observed in the paste even after only three days of treatment. Evidence of this can be seen in the NM- 6657-02 2 week sample, where the PCB levels dropped from an initial value of 2,797 mg/kg to 46 mg/kg after only three days of treatment with Mg. The other piece of information that is of significant importance is that the Mg particles performed as well as or better than the Mg/Pd particles. This is extremely important because the removal of the Pd from the BTS system reduces the cost of the treatment metal particles by more than 50%. In addition it eliminates potential concerns related to the release of Pd into the environment.

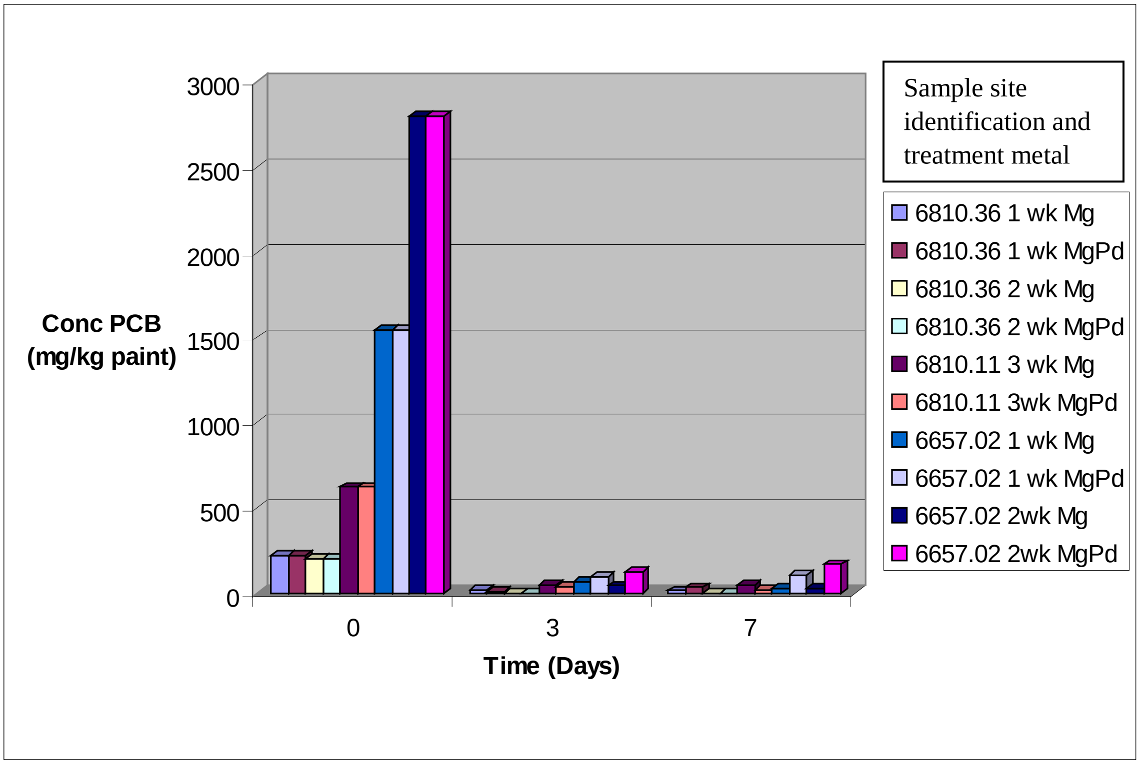


Figure 5-16. Results of PCB degradation by Mg and Mg/Pd particles added to the non-metal Badger paste samples.

6 PERFORMANCE ASSESSMENT

The section provides a summary of all data analysis conducted in support of the assessment of performance objectives.

6.1 Distribution and Adherence of the BTS

One of the qualitative performance objectives is that the BTS applicator is able to evenly distribute the paste on the surface to be treated. The metric was evaluated by assessing the adherence of a 0.25 to 0.5 inch layer of the BTS to an object over the time period of exposure to treated surfaces. BTS paste was applied to surfaces to be treated using two types of application methods and its thickness estimated. The paste was visually inspected periodically (every two to 5 days for the first week and then weekly for up to a month) to determine if it was able to adhere to the surfaces (both vertical and horizontal treated surfaces) by inspecting for leaks, sections of paste pulling away from the surface or bubbling up off the surface.

This objective was met. BTS was applied using a spray applicator and hand trowel application method. In some cases the paste did not adhere well to the vertical painted surfaces but this was due to adhesion issues with the paint (old and friable paint on concrete surface) and not due to the pastes ability to adhere to the surface. Applications were done using the hand trowel method at Badger due to the paste thickening in the cold. At the VIB, where both the spray applicator method and hand trowel application were used, the spray applicator resulted in a much thinner layer of BTS being applied compared with the trowel application which did affect the treatment ability of the BTS so preference was given to the hand application method. At the VIB, the paste adhered to vertical and horizontal surfaces without any problems in a consistency that could be spray applied or spread with a trowel by hand. It was determined that it was faster to apply the paste with the trowel in a layer of the desired thickness rather than using a spray applicator which required multiple passes to get the desired thickness.

6.2 Adherence of Sealants

The metric was evaluated by assessing the adherence of the sealant to the BTS, the ability to apply the sealant evenly over the surface of the paste, and its ability to dry to a non-tacky, non-porous layer that reduced volatilization of BTS solvent. Two sealants were tested, a vinyl polymer (VP) truck bed liner and a silicone-based roof sealant (Sil). The sealant and underlying BTS paste were inspected every one to two days, depending on location, for the first five days and samples were collected of the paste and sealant weekly for up to a month after application. The sealants ability to adhere to the BTS and to reduce volatilization of the ethanol in the BTS was evaluated by visual inspection (looking for leaks around the edges of the sealant, looking for bubbles or drooping of sealant away from BTS surface) and manual inspection by pressing lightly on the sealed surface to test the fluidity of the paste.

This objective was met using both sealants but some difficulties were encountered with old friable paint and cold temperatures. Both sealants were able to provide an effective seal to minimize ethanol evaporation from the BTS paste for the three weeks of application. In the cases where there were issues with the condition of the paint (old and friable paint on concrete) there were issues with both the sealant and paste sticking to the surface and the seal failed. However, this had to do with the paint itself being unable to adhere to the surface and not the sealant. In addition, the cold temperatures during the Badger deployment did affect the ability of the sealant to remain flexible and some cracking of the sealant did occur. If possible, it would be preferable to apply BTS in above freezing conditions to avoid the risk of sealant failure. If applications must be done in below freezing temperatures, additional care must be taken to inspect and repair cracks in the sealant as they appear.

6.3 Ease of implementation

The ease of use of this technology was evaluated based on our experience in the field. The implementability was evaluated by the qualitative assessment of the ease with which the operator was trained to handle and apply both the paste and the sealant in the various field situations.

This objective was met with respect to both the ease of handling and applying both the paste and sealant on the various surfaces and locations that were treated. The equipment required for the manufacturing of BTS on Site using the acidified ethanol and Mg would be readily available through the paint industry. The application equipment used to apply BTS and the sealants was all readily available through local hardware suppliers or the paint industry. The procedures used to manufacture the BTS were well established procedures and were simple enough to be conducted by field technicians with training in the manufacturing techniques. The procedures used to apply the BTS were standard and well established procedures and the procedures were simple enough to be conducted by field technicians with training in basic application techniques and handling techniques of the BTS and sealants.

6.4 Reduction in PCB Concentrations in Treated Paint to Less Than 50 mg/kg

A key performance objective is the reduction of PCB concentrations in the treated material to less than 50 mg/kg. The metric was evaluated by collecting samples of the paint pre-BTS application and then weekly for up to a month for analysis of PCB concentrations. This was a destructive analysis and was done on one section of the test area on a weekly basis until all sections had been analyzed.

This objective was partially met. One application of paste was effective in achieving this target after only one week of treatment in all cases where the starting concentration in the paint was less than approximately 500 mg/kg, especially if the surface being treated was metal and not concrete. In cases where the starting concentrations in the paint were greater than 500 mg/kg, significant reductions (93%) in PCB concentrations were achieved but more than one application of paste is necessary to reduce concentrations below 50 mg/kg. It is believed that in part this was because the PCBs extracted into the paste may have exceeded the degradation capabilities of the Mg/Pd in the paste for the Mg/Pd BTS and then the paste became concentrated with PCBs. For the NM BTS the paste became concentrated with PCBs before complete extraction of PCBs from the paint could occur. The PCB-saturated paste was no longer able to further extract PCBs from the paint. The performance of the BTS paste was also negatively impacted by the conditions of the paint at building 6810-36 and 6810-11. The paint was friable and peeling which prevented the BTS from achieving a good adherence to the wall and prevented the sealant from providing and effective seal of the paste which resulted in the loss of ethanol from the paste. In addition, the paste was applied to a porous surface that reduced the amount of ethanol available in the paste (loss of ethanol to the concrete, magnified by the amount of concrete that was treated that was exposed without any paint to seal it).

6.5 Reduction in PCB Concentrations in BTS Paste to Less Than 50 mg/kg

The reduction of PCB concentrations in the paste to less than 50 mg/kg is another key performance objective. The metric was evaluated by collecting samples of the paste weekly for up to a month for analysis of PCB concentrations. This was a destructive analysis that was done on one section of the test area on a weekly basis until all sections had been analyzed. For BTS that did not contain the activated metals for degradation (non-active paste) a subset of the paste sample was analyzed for PCBs and then the activated metal and, if necessary, additional ethanol, were added to the non-active paste to promote degradation (post-application activated paste). Samples of the post-application activated paste were then analyzed for PCB concentrations.

This objective was partially met. For the active paste (metal in the paste) if the starting paint concentrations were below roughly 2,500 mg/kg then the concentrations in the paste were less than 50 mg/kg with the exception of the 3 weeks samples from Badger Building 6810-11 where concentrations were still slightly above the 50 mg/kg target (60 mg/kg;). If the pre-treatment paint concentrations were very high (> 20,000 mg/kg) then the active metal paste was not able to degrade all of the PCBs in the paste to below 50 mg/kg although some dechlorination did occur in the paste. If very high concentrations are present in the paint this yields a situation where more PCBs are present than can be handled by the Mg/Pd available in the paste or that can degraded sufficiently in the time period that solvent remains in the paste to facilitate treatment. As mentioned above, the paste becomes concentrated with PCBs. Even when Mg/Pd and additional ethanol was added in the laboratory to the active paste that had been exposed to the very high starting concentrations it was not possible to get the concentrations in the paste to below 50 mg/kg after 21 days. The rates of dechlorination were enhanced somewhat by the addition of acidified ethanol, but they only reached a level of one-fourth that of fresh Mg/Pd paste. The reason for this inability to reactivate the aged Mg/Pd particles to original rate levels is still being studied but present evidence suggests that a hard layer of impervious magnesium oxide (MgO) is formed on the outside of the particle. The use of acidified ethanol after the MgO layer is formed is only effective at penetrating a small fraction of the layer. However, when acidified ethanol is used during the initial preparation of the BTS paste, the formation of the impervious layer of MgO appears to be minimized to a level where reaction rates remain high.

For the non metal paste, which was activated in the lab after removal from the field by the addition of ethanol and the active metal (Mg and acid or Mg/Pd), the concentrations were reduced to below 50 mg/kg for all samples using either the acidified ethanol and Mg and/or ethanol and the Mg/Pd.

6.6 Impact to Paint Adherence

One of the secondary objectives was to evaluate the impact to the paint adherence after exposure to BTS. The metric was evaluated by visually assessing the condition of the paint after BTS application as well as by using the field test for pull-off strength of coatings (ASTM D3359-02).

When the paint at the Badger test sites was subjected to the ASTM D3359-02 procedure prior to application of BTS, the paint at all the test sites failed. Thus, the effect of the BTS on the integrity of the painted surfaces at Badger could not be assessed.

There were difficulties in using ASTM D3359-02 at the VIB on post-treatment samples due to preparation of the surface prior to testing and ASTM D4541-02 was also used to evaluate the paint adherence for the VIB panels.

This objective was not met in that the BTS negatively affected the adherence and strength of at least the surface layer of paint.

7 COST ASSESSMENT

This section presents the results of a cost assessment to implement remediation of PCB containing painted structures using BTS. Cost data collected during the technology demonstration were evaluated as described in the following sections. Section 7.1 describes a cost model that was developed for the application of BTS with a comparison to disposal of structures without treatment; Section 7.2 presents an assessment of the cost drivers for the application of the technology; and Section 7.3 presents the results of an analysis of the cost model.

7.1 Cost Model

A cost model was developed to assist remediation professionals in understanding costs associated with the BTS technology. The cost model identified the major cost elements required to implement the BTS technology at typical structures. A summary of the actual costs for pilot-scale implementation of the BTS technology at Badger and the VIB is presented in Table 7-1.

The major cost categories tracked during the field demonstrations at Badger and the VIB were:

Capital Costs –

Design and Planning – This cost element includes activities required to scope the project, such as site visits required to evaluate size and configuration of the surface coating which may impact the application process of the solvent paste, how many applications of solvent paste may be required, and whether a single-phase treatment (active solvent paste containing catalyst) or two-phase (inactive solvent paste with catalyst added later) treatment may be more cost effective.

Treatability Testing - This cost element includes the labor required to collect and analyze samples of PCB-containing material samples before and after bench-scale treatment. This laboratory evaluation will inform the final design of the application of the solvent paste, number of probable applications required, and whether to use a single-phase or two-phase treatment. This cost element provides scale-up information required for the manufacture of the catalyst and the solvent paste.

Manufacturing of the Catalyst System and BTS Reagent for Field Testing - Based on scale-up information developed during treatability testing, the volume and consistency of solvent paste required and whether it will be applied as an inactive or active paste have been determined. The amount of catalyst required to treat the expected PCB concentrations has also been determined. Costs include raw materials for the solvent paste and catalyst and manufacturing labor.

TABLE 7-1
ACTUAL COSTS FOR BTS TECHNOLOGY DEM/VAL

Cost Element	Data Tracked During the Demonstration/Per Site	Cost	
Capital Costs			
Design & Planning	- Personnel required and associated labor	Labor	$1,433
		Other Costs	$270
Treatability Testing	- Personnel required and associated labor for treatability testing activities	Labor	$27,300
		Other Costs	$12,000
Manufacturing of the Catalyst System and BTS Reagent for Field Testing	- Personnel required and associated labor for BTS application activities - Mobilization costs - Costs for BTS and applicaiton equipment	Labor	$8,568
		Other Costs	$7,000
Application of BTS to DoD Test Structures/Materials	- Personnel required and associated labor for BTS application activities - Mobilization costs - Costs for BTS and application equipment	Labor	$7,600
		Other Costs	$9,300
Removal of BTS to DoD Test Structures/Materials	- Personnel required and associated labor for BTS removal activities - Demobilization costs	Labor	$2,400
		Other Costs	$1,200
Performance Monitoring			
Baseline Characterization	- Personnel required and associated labor - Mobilization costs - Supplies and equipment for sampling - Sample shipment and laboratory analytical costs - Labor associated with data reporting	Labor	$7,400
		Other Costs	$3,900
Performance Monitoring	- Personnel required and associated labor - Mobilization costs - Supplies and equipment for sampling - Sample shipment and laboratory analytical costs - Labor associated with data reporting	Labor	$18,800
		Other Costs	$17,800

Application/Removal of BTS to DoD Test Structures /Materials - In this cost element, the catalyst, solvent paste, and sealant are mobilized to the site, along with the appropriate application/removal and waste handling equipment and demobilization costs. Costs include labor hours to apply/remove the solvent paste and sealant.

Performance Monitoring Costs

Baseline Characterization - This cost element addresses activities and equipment required to collect and analyze samples of coating material to assess and report the presence and concentration of PCBs prior to any treatment. Information developed during this process informs initial design for the project.

Performance Monitoring - This cost element addresses activities and equipment required to collect and analyze samples of coating material to assess and report the presence and concentration of PCBs during in situ treatment. Results inform the number of applications of solvent paste which may be required.

The cost model that is shown in Table 7-1 were based on the actual costs that were tracked in the Demonstrations. More weight was given to the costs from the Badger Demonstration since this demonstration occurred at a more remote facility (VIB Demonstration was done at a facility located very near to the NASA office and laboratory).

The cost model was then applied for two template sites requiring disposal or demolition of buildings or structures covered in paint containing 250 mg/kg PCBs. Two model structures were used; the first a painted concrete (porous surface) building that was to be demolished; and the second a painted metal tank (non-porous surface) that required disposal. For ease of comparison, both structures were assumed to have a painted surface area of 8000 square feet.

The starting PCB concentration of 250 mg/kg was chosen because during this demonstration, this concentration was been shown to be able to be treated in place with one application of an active paste. It was assumed that it will require one week of exposure of the BTS to the painted surface to completely extract the PCBs from the paint. The BTS would then be transferred to drums or roll-off bins and allowed to sit for another week to allow for complete degradation of the PCBs in the BTS paste prior to disposal as non-hazardous waste.

A set of eight pre-treatment paint and concrete samples are assumed to be required to characterize the site (8,000 ft^2 to be treated) prior to treatment and eight post treatment samples of the paint, concrete and paste to evaluate the performance of the treatment.

Cost estimates for the BTS technology were prepared for both painted concrete and painted metal because of the potential differences in how these materials may need to be handled.

Based on the EPA's Polychlorinated Biphenyl (PCB) Site Revitalization Guidance Under the Toxic Substances Control Act (TSCA) (November 2005), porous and non-porous surfaces are treated differently. If disposal or reuse is considered for a building where PCB-containing paint is used on a porous surface, the paint must be removed and treated as PCB bulk product waste. The porous material must then be tested (i.e., concrete core samples) and, if PCBs have migrated into the porous surface, then the porous materials must be handled as PCB remediation waste and disposed of in a TSCA-approved landfill. For non-porous surfaces, the paint can be removed and treated as a PCB bulk product waste and if the non-porous surface is shown to be clean, the item can be reused, recycled or disposed of as non-hazardous waste.

Costs have been organized into three major categories: Start-up/Shut Down, Operations and Maintenance, and Waste Handling. Start-up/Shut Down includes materials and labor costs associated with mobilization and demobilization, permitting, BTS operator training, site preparation, sample collection, and treatability testing. Operations and Maintenance includes materials and labor costs associated with BTS preparation, application, and analysis, demolition or paint removal, equipment decontamination and the testing/analysis of waste streams and metal surfaces, as appropriate. Waste Handling includes materials and labor costs associated with transportation and disposal of hazardous and non-hazardous demolition debris and waste, decontamination/wash fluids, BTS waste and metal recycling.

7.2 Cost Drivers

The costs to implement the BTS technology for treatment of PCBs in paint will vary significantly from site to site. The key costs drivers are listed below, along with a brief discussion of their impact on cost.

Nature and Extent of Contamination

- **Concentrations of PCBs in paint** – The higher the PCB concentrations are in the painted surfaces, the more likely it will be that multiple applications of BTS may be required to achieved removal and/or degradation of the PCBs to below 50 mg/kg.

- **Conditions of the surface to be treated** – If the paint to be treated is old, weathered, damaged and/or friable, proper adherence of the BTS and sealant to the surface may be difficult to achieve. This may make it difficult to achieved removal of PCBs to below 50 mg/kg with a single application of the BTS.

- **Geometry and simplicity of the surface to be treated** – If the surface of the structure to be treated is very convoluted, with many grooves or hard-to-access surfaces (pipes strapped to walls that are painted with PCB paint) this will increase the effort required to properly apply the BTS to the surfaces to be treated.

- **Additional constituents which require treatment –** For example, at Badger, materials with the potential of containing residue of explosive or energetic compounds must be incinerated prior to disposal. However, the presence of PCBs in concentrations > 50 mg/kg require incineration in an oven operating in conformance with 40 CFR 761.72(a) and if the material must be cut into manageable sizes, a special permit is required to perform the cutting operations. These conditions may make BTS application more favorable.

Environmental Conditions

- **Temperature and Weather Conditions –** Although the BTS has been shown to degrade PCBs at cold temperatures (4ºC) the rate is slower and there may be difficulties with the performance of the sealants in cold temperatures that could affect the number of times sealant or BTS may need to be applied.

Available Infrastructure & Site Access

- **Available infrastructure** - The availability of existing infrastructure (e.g., on site or nearby landfills, storage buildings, and utilities) can reduce the cost of technology implementation.

- **Site Access** - Sites having limited access for equipment and personnel (e.g., difficult terrain, obstructions, or other complicating factors such as explosives storage) may incur higher costs when implementing the technology.

- **Site Location –** If the site is located in a remote area, there will be additional mobilization costs. However, there will also be a significant increase in costs for transport to and disposal of hazardous waste in a properly permitted landfill, which may make the cost benefit of treating a structure with BTS more favorable. The costs for transportation and disposal of PCB impacted waste could be much more significant if the distances are greater or the site is very remote or difficult to access such as on an island, or in the arctic.

7.3 Comparison of Cost Analysis

BTS, when deployed at the perceived end of a facility's lifecycle, may represent an additional, rather than an alternative, cost in that facility's final disposition. As such, an extremely simplified cost model has been applied to the costs associated with alternative facility disposal methods and a BTS treatment scenario. For the purposes of this costs analysis, only those costs and environmental liability due to PCB concentrations in excess of the regulatory limit of 50 mg/kg are being considered. However, given that BTS can extend structure reuse by removing PCBs without damaging the structure may also be considered an alternative to final disposition.

The most probable scenarios associated with the application of BTS are as follows:

1. Baseline conditions (untreated facility). Environmental liability due to PCB concentrations is retained.
    - Demolition of facility or structure.
    - Steel and concrete is not recycled due to PCB concentrations.
    - Demolition debris is landfilled as hazardous waste.
2. BTS is applied to the facility's coatings and other materials as appropriate. Environmental liability due to PCB concentrations is eliminated. Two scenarios may be available: Structure reuse or demolition.
    - Structure reuse: Life cycle of building is extended, reducing unit capital cost associated with the structure.
    - Demolition of facility or structure.
        - Steel and concrete may be recycled, providing an opportunity to defray costs associated with PCB treatment and/or demolition.
        - Demolition debris is landfilled as non-hazardous waste.

The success of BTS was evaluated by comparing the added cost of BTS treatment to the reduced costs associated with the landfilling of demolition debris, the potential revenue generation from steel and concrete recycling, and perhaps the extended life/re-use of the facility which would not otherwise be cost-effective.

Using the template site conditions described above, estimates of costs were developed for each of the following alternatives:

- Concrete structure demolition, untreated and disposed of in a TSCA landfill;
- Concrete structure demolition, treated prior to demolition with BTS, disposed of non-hazardous landfill and concrete recycled;
- Concrete structure treated with BTS and reused. This alternative addresses those structures where PCB concentration in paints or other materials drive the requirement for demolition;
- Metal tank, untreated and disposed of in a TSCA landfill;
- Metal tank, conventional paint removal using sandblasting, sandblast waste sent to TSCA landfill and metal tank recycled; and
- Metal tank, treated with BTS and then recycled.

Based on the cost models shown in Table 7-2 and 7-3, it appears that it would be cost effective to apply BTS to a concrete building prior to demolition compared with the costs of demolishing the building and disposing of the waste in a TSCA landfill. Demolition and disposal costs of the untreated concrete building are estimated to be approximately $200,000, while the cost of treating the painted concrete with BTS, followed by demolishing the building and recycling the

TABLE 7-2
COMPARISON OF COST SCENARIOS - POROUS

		Painted Porous Surface (Concrete Building)								
		Concrete Building Untreated Demolished, Sent for Disposal Directly to TSCA Landfill			Concrete Building Treated with BTS - Demolished, Sent for Disposal in Non-Haz Landfill and Concrete Recycled			Concrete Building Treated with BTS and Reused		
	Unit	Quantity	Unit Price	Cost	Quantity	Unit Price	Cost	Quantity	Unit Price	Cost
Start-Up/Shut Down										
Mobilization	LS	1	$ 4,000	$ 4,000	1	$ 5,500	$ 5,500	1	$ 1,500	$ 1,500
Sample Collection and Treatability Tests	LS	0		$ -	1	$ 12,500	$ 12,500	1	$ 12,500	$ 12,500
Permitting, Approvals	LS	1	$ 3,200	$ 3,200	1	$ 4,000	$ 4,000	1	$ 4,000	$ 4,000
Site Preparation (Disconnect/Abandon Utilities, Dust and Erosion Control)	LS	1	$ 7,400	$ 7,400	1	$ 5,500	$ 5,500	0		$ -
Train BTS Operators	HR	0	$ 255	$ -	8	$ 255	$ 2,040	8	$ 255	$ 2,040
Demobilization	LS	1	$ 4,000	$ 4,000	1	$ 5,500	$ 5,500	1	$ 1,500	$ 1,500
Sub-Total				***$ 18,600***			***$ 35,040***			***$ 21,540***
Operations and Maintenance										
Labor – BTS Application	HR	0	$ 55	$ -	20	$ 55	$ 1,100	20	$ 55	$ 1,100
Labor - Demolition and Segregation of Debris	LS	1	$ 6,200	$ 6,200	1	$ 6,200	$ 6,200	1	$ 6,200	$ 6,200
onsumables and Supplies (PCB-impacted dust mitigation etc)	LS	1	$ 1,400	$ 1,400	0		$ -	0		$ -
Lab Analysis of Progress of PCB Degradation	Sample	0	$ 65	$ -	8	$ 65	$ 520	8	$ 65	$ 520
BTS Materials Including Sealant	SF	0	$ 15	$ -	8000	$ 15	$ 118,960	8000	$ 15	$ 118,960
Consumables and Supplies (Application of BTS)	LS	0	$ 1,500	$ -	1	$ 1,500	$ 1,500	1	$ 1,500	$ 1,500
Equipment Decontamination	LS	1	$ 1,000	$ 1,000	0		$ -	0		$ -
Test/Analysis of Waste Streams	Sample	0		$ -	8	$ 100	$ 800	8	$ 100	$ 800
Sub-Total				***$ 8,600***			***$ 129,080***			***$ 129,080***
Waste Handling										
Transportation of Demolition Debris to Non-Haz Landfill	TON	118	$ 22	$ 2,596	118	$ 22	$ 2,596	0	$ 22	$ -
Disposal of Demolition Waste in Non-Haz Landfill	TON	118	$ 80	$ 9,440	118	$ 80	$ 9,440	0	$ 80	$ -
Delivery of Bins and Transportation of Demolition Debris to TSCA Landfill	TON	182	$ 530	$ 96,460	0		$ -	0		$ -
Disposal of Demolition Waste in TSCA Landfill	TON	182	$ 350	$ 63,700	0		$ -	0		$ -
Transportation of Decontamination/Wash Fluid (non-haz)	GAL	100	$ 5	$ 475	100	$ 5	$ 500	50	$ 5	$ 250
Disposal of Decontamination/Wash Fluid (non-haz)	GAL	100	$ 1	$ 100	100	$ 1	$ 100	50	$ 1	$ 50
Transportation of Concrete for Recycling (~60% of Material)	TON	0		$ -	182	$ 22	$ 4,004	0	$ 22	$ -
Transportation of BTS Waste (non-Haz)	TON	0		$ -	0.5	$ 22	$ 11	0.5	$ 22	$ 11
Disposal of BTS Waste in Non-Haz Landfill	TON	0		$ -	0.5	$ 80	$ 40	0.5	$ 80	$ 40
Sub-Total				***$ 172,771***			***$ 16,691***			***$ 351***
TOTAL				$ 199,971			$ 180,811			$ 150,971

Notes

Assume starting concentration in paint is 250 mg/kg

Assumes treatment of 8000 square feet surface area for both building and tank

Large variability in transportation and disposal costs depending on distance to landfill and the concentrations in the waste but costs for transportation and disposal to TSCA landfill is based on

Assumes that State/EPA regulations would require the porous substrate to be disposed as hazardous waste in TSCA-regulated landfill if painted surface has >50 ppm PCBs

Assume for painted concrete, 45 lbs of substrate per square foot of painted area or 44 sq ft per ton of substrate

LS - lump sum

SF - square foot

TABLE 7-3
COMPARISON OF COST SCENARIOS - METAL

		Painted Non-Porous Surface (Metal Tank)								
		Metal Tank Untreated (Paint Not Removed) and Disposed of in TSCA Landfill			Metal Tank, Paint Removed by Sandblasting and Tank Recycled			Metal Tank Treated with BTS and Recycled		
	Unit	Quantity	Unit Price	Cost	Quantity	Unit Price	Cost	Quantity	Unit Price	Cost
Start-Up/Shut Down										
Mobilization	LS	1	$ 1,500	$ 1,500	1	$ 1,500	$ 1,500	1	$ 1,500	$ 1,500
Sample Collection and Treatability Tests	LS	0		$ -	0		$ -	1	$ 9,500	$ 9,500
Permitting, Approvals	LS	1	$ 3,000	$ 3,000	1	$ 3,000	$ 3,000	1	$ 1,500	$ 1,500
Site Preparation (Disconnect/Abandon Utilities, Dust and Erosion Control)	LS	0	$ 500	$ -	1	$ 500	$ 500	1	$ 2,500	$ 2,500
Train BTS Operators	HR	0		$ -	0		$ -	8	$ 255	$ 2,040
Demobilization	LS	1	$ 1,500	$ 1,500	1	$ 1,500	$ 1,500	1	$ 5,500	$ 5,500
Sub-Total				***$ 6,000***			***$ 6,500***			***$ 22,540***
Operations and Maintenance										
Labor – BTS Application	HR	0	$ 55	$ -	0	$ 55	$ -	16	$ 55	$ 880
Labor - Demolition and Segregation of Debris	LS	10	$ 55	$ 550	-	-	-	-	-	-
onsumables and Supplies (PCB-impacted dust mitigation etc)	LS	0	$ 1,400	$ -	1	$ 2,000	$ 2,000	-	-	-
Lab Analysis of Progress of PCB Degradation	Sample	0		$ -	0		$ -	8	$ 65	$ 520
Sandblasting Costs (including labor)	SF	0	$ 8,000	$ -	8000	$ 10	$ 80,000	0	$ 8,000	$ -
BTS Materials Including Sealant	SF	0	$ 15	$ -	0	$ 15	$ -	8000	$ 15	$ 118,960
Consumables and Supplies (Application of BTS)	LS	0	$ 1,500	$ -	0	$ 1,500	$ -	1	$ 1,500	$ 1,500
Equipment Decontamination	LS	0	$ 500	$ -	1	$ 500	$ 500	0		$ -
Test/Analysis of Waste Streams	Sample	3	$ 100	$ 300	8	$ 100	$ 800	8	$ 100	$ 800
Test/Analysis of Metal Surface	Sample	0	$ 100	$ -	5	$ 100	$ 500	5	$ 100	$ 500
Sub-Total				***$ 850***			***$ 83,800***			***$ 123,160***
Waste Handling										
Transportation of Demolition Debris to Non-Haz Landfill	TON	0	$ 22	$ -	-	-	-	-	-	-
Disposal of Demolition Waste in Non-Haz Landfill	TON	0	$ 80	$ -	-	-	-	-	-	-
Delivery of Bins and Transportation of Demolition Debris to TSCA Landfill	TON	20	$ 530	$ 10,600	-	-	-	-	-	-
Disposal of Demolition Waste in TSCA Landfill	TON	20	$ 350	$ 7,000	-	-	-	-	-	-
Transportation of Decontamination/Wash Fluid (non-haz)	GAL	50	$ 5	$ 238	50	$ 5	$ 238	50	$ 5	$ 250
Disposal of Decontamination/Wash Fluid (non-haz)	GAL	50	$ 1	$ 50	50	$ 1	$ 50	50	$ 1	$ 50
Transportation of Concrete for Recycling (~60% of Material)	TON	-	-	-	-	-	-	-	-	-
Transportation of BTS Waste (non-Haz)	TON	0	$ 22	$ -	0	$ 22	$ -	0.5	$ 22	$ 11
Disposal of BTS Waste in Non-Haz Landfill	TON	0	$ 80	$ -	0	$ 80	$ -	0.5	$ 80	$ 40
Transportation of Sandblasting Waste to TSCA Landfill	TON	0	$ 530	$ -	24	$ 530	$ 12,720	0	$ 530	$ -
Disposal of Sandblasting Waste in TSCA Landfill	TON	0	$ 430	$ -	24	$ 350	$ 8,400	0	$ 350	$ -
Transportation of Metal Tank to Recycling	TON	0	$ 12	$ -	20	$ 12	$ 240	20	$ 12	$ 240
Recycled Steel Scrap	TON	-	-	-	20	$ (350)	$ (7,000)	20	$ (350)	$ (7,000)
Sub-Total				***$ 17,888***			***$ 14,648***			***$ (6,409)***
TOTAL				**$ 24,738**			**$ 104,948**			**$ 139,291**

Notes

Assume starting concentration in paint is 250 mg/kg

Assumes treatment of 8000 square feet surface area for both building and tank

Large variability in transportation and disposal costs depending on distance to landfill and the concentrations in the waste but costs for transportation and disposal to TSCA landfill is based on

Assumes that State/EPA regulations would require the porous substrate to be disposed as hazardous waste in TSCA-regulated landfill if painted surface has >50 ppm PCBs

Assume for painted concrete, 45 lbs of substrate per square foot of painted area or 44 sq ft per ton of substrate

LS - lump sum

SF - square foot

concrete is estimated to be approximately $180.000. In the third scenario, BTS treatment and building reuse rather than demolition, estimated costs are even lower at approximately $150,000.

In contrast, if the structure to be treated is a metal tank, then it does not seem to be cost effective to address the PCB-containing paint by either conventional sandblasting or BTS treatment in order to recycle the tank. Straight disposal of the untreated tank is estimated to cost approximately $25,000 versus removal of the paint with sandblasting and recycling the tank which is estimated to cost $105,000 and treatment with BTS and recycling the tank which is estimated to cost $140,000. It must be noted that both untreated tank debris and sandblast waste will retain PCBs and associated environmental liability issues, while there are no long term liability issues if the tank is treated with BTS before disposal.

As mentioned above, the costs for transportation and disposal of PCB impacted waste could be much more significant if the distances are greater or the site is very remote or difficult to access such as on an island, or in the arctic.

All the scenarios evaluated in the costs model have assumed the treatment of PCB-containing materials down to the Federal regulatory limit of 50 mg/kg. However, some states or countries may have stricter regulations with respect to the disposal of PCB impacted wastes. According to http://www.ehso.com/EHSO_PCB.htm (Environmental Health and Safety online) the Federal regulation for non-PCB waste is 50 mg/kg, but some state regulations are 5 mg/kg. For the situation with the Navy properties in Japan, the regulations are very strict and any waste with PCB concentrations >0.5 mg/kg cannot be disposed of in Japan. This requires that the US Navy transport all materials impacted by PCBs to another location for disposal greatly increasing the costs. Thus, a more restrictive regulatory limit will tend to increase the cost effectiveness of BTS treatment of facilities over straight demolition and disposal. BTS can reduce PCB concentrations down to non-detect (detection limit of 1 mg/kg) but the lower the target treatment concentration is the greater the potential exists for the need for additional applications of BTS, and therefore greater costs, to achieve these targets.

8 IMPLEMENTATION ISSUES

This section provides information that will aid in the future implementation of the technology.

8.1 Potential Environmental Issues

8.1.1 Regulatory Issues

Permits would be required to treat and dispose of wastes that have been or are impacted with PCBs. The type of permit and limits of PCB concentrations in the waste for disposal will vary by State and sufficient time should be allowed to get the permits.

8.1.2 Air Discharge

The BTS process described will not normally result in discharge of chemicals to the atmosphere with the exception of some loss of solvent (ethanol) from the paste.

8.1.3 Waste Storage, Treatment, and Disposal

The BTS process will result in the generation of a small amount of waste that can be allowed to dry and then disposed of as non-hazardous waste that must be managed consistent with other non-hazardous waste.

8.2 End-User Issues

Potential end-users of this technology include responsible parties for sites where PCBs are present in structures in paint or other building components. End-users will have an interest in the technology because it can potentially treat PCBs *in situ* and allow for reuse of buildings and other structures without concern regarding the future liabilities related to PCBs or allow for a lower cost less than for conventional demolition and disposal approaches and other PCB handling technologies like sandblasting. End-users and other stakeholders may have concerns regarding: 1) the effectiveness of the technology in reducing concentrations of PCBs below appropriate criteria; and 2) the costs of the treatment versus disposal of untreated materials and the evaluation of the long term liability associated with disposal of untreated materials.

8.3 Procurement Issues

There are no specialized equipment components required to implement BTS and no specialized services required. There are a number of magnesium powder and other ingredient vendors. There are no significant procurement issues with the application of this technology.

8.4 Design Issues

Application in cold weather (i.e., below freezing) may be difficult because of difficulties in maintaining an effective seal with the sealant used to prevent the solvent from evaporating during treatment.

Treatment of paint with high concentrations of PCB (i.e., greater than ~ 500 mg/Kg) that may require multiple applications of BTS paste or the use of thicker layers of BTS paste to achieve treated paint criteria of 50 mg/Kg.

Treatment of painted surfaces where the paint is friable or is not adhering to the surface to be treated. In these situations it may be appropriate to remove loose paint from the surface prior to treatment of the surface with the BTS paste. The paint removed from the surface prior to application of the BTS paste could be treated on site using a non-thickened version of the BTS reagent to extract PCBs from the paint chips and degrade the PCB.

Application of BTS paste to irregular surface areas requires a thinner, sprayable form of the solvent paste to adequately cover the exterior. Sealants tested in this demonstration are all sprayable materials and do not pose any application difficulty and will maintain required moisture levels for PCB extraction from the surface coating. As with any surface, the need for removal of spent solvent and reapplication of fresh solvent paste is dependent upon initial PCB concentrations and required final PCB concentrations. If the irregular surface to be treated is small and accessible, it may be removed and placed in a tank of solvent paste (dip tank), to ensure complete saturation of the coating.

Application of BTS paste to large, flat surfaces, such as a vertical wall may be most easily accomplished with a sprayable form of the paste, then covered with a sprayable sealant to maintain required moisture levels for PCB extraction.

Formulation of the BTS paste to be applied to the painted surface. This work has demonstrated that it is possible to use a treatment formulation that contains Mg in an acidified ethanol solvent. This formulation of Activated Metal Treatment System (AMTS) may be more attractive than the Mg/Pd formulation because of lower cost and avoiding the use of Pd.

Use of a single step or two step process for the treatment of surfaces. This work has suggested that it is possible to use a two step process of extraction of PCBs using a non-metal paste and then activating the non-metal paste in a separate container following extraction (Figures 2-1, 2-1, Section 5.1).

Regulatory limits and therefore target treatment concentrations are also an important design issue. The Federal regulation for the disposal of a waste as a non-PCB waste is 50 mg/kg, but some state regulations are 5 mg/kg. For the situation with the Navy properties in Japan, the regulations are very strict and any waste with PCB concentrations >0.5 mg/kg cannot be disposed of in Japan. This requires that the US Navy transport all materials impacted by PCBs to another location for disposal greatly increasing the costs. Thus, a more restrictive regulatory limit will tend to increase the cost effectiveness of BTS treatment of facilities over straight demolition and disposal. When designing a treatment where regulatory or target treatment concentrations are very low, it is important to design for the potential need of additional applications of BTS to achieve the remediation target. For instance for an application with a starting concentration of 500 mg/kg, one application of BTS may be sufficient to get the concentrations below 50 mg/kg but a second application may be necessary to get it below 5 mg/kg.

9 FOLLOW-ON WORK

Studies conducted at UCF after the project was initiated have shown that the Pd catalyst can be removed from the BTS paste and a small amount of acid added to make a paste that is both less expensive and more reactive. The addition of a small amount of acetic acid to the ethanol significantly increased the rate of PCB degradation. These studies also showed that acidified ethanol with Mg particles was as effective or in some cases more effective than the Mg/Pd particles in non-acidified ethanol at degrading PCBs. Present evidence suggests that a hard layer of impervious magnesium oxide (MgO) is formed on the outside of the Mg particles over time. The use of acidified ethanol after the MgO layer is formed is only effective at penetrating a small fraction of the layer. However, when acidified ethanol is used during the initial preparation of the BTS paste, the formation of the impervious layer of MgO appears to be minimized to a level where reaction rates remain high. This discovery is extremely important because it means that Pd is not required in the BTS formulation, which reduces the cost of the BTS paste significantly.

BTS has been modified by removing the Pd and is referred to as Activated Metal Treatment System (AMTS). AMTS consists of activated elemental magnesium in a green-solvent solution capable of hydrogen donation. As mentioned above, the AMTS is less expensive than BTS through further modifications to the formula (i.e., different sorbent material as well as removal of the Pd). If the costs for AMTS are used in place of BTS in the cost tables in Section 7, it would be cost effective to apply AMTS to a concrete building prior to demolition compared with the costs of demolishing the building and disposing of the waste in a TSCA landfill. Demolition and disposal costs of the untreated concrete building are estimated to be approximately $200,000, while the cost of treating the painted concrete with BTS, followed by demolishing the building and recycling the concrete is estimated to be approximately $180.000. If AMTS is used in this scenario instead of BTS the cost is estimated to be approximately $75,000.

In contrast, if the structure to be treated is a metal tank, then it does not seem to be cost effective to address the PCB-containing paint by either conventional sandblasting, BTS treatment or AMTS treatment in order to recycle the tank. Straight disposal of the untreated tank is estimated to cost approximately $25,000 versus removal of the paint with sandblasting and recycling the tank which is estimated to cost $105,000 and treatment with BTS and recycling the tank which is estimated to cost $140,000. Treatment with AMTS and recycling the tank is estimated to cost $33,000.

NASA and Scientific Specialists jointly hold the patents for both BTS and AMTS and there is already commercial sector interest; the technologies are licensed to two companies with other licenses in process

10 REFERENCES

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11 POINTS OF CONTACT

A summary of contact information for key personnel associated with the technology demonstration is presented in **Table 11-1**.

Point of Contact	Organization	Phone/Fax/E-mail	Role in Project
Dr. Nancy Ruiz	NFESC	(805) 982-1155 Fax (805) 982-4304 nancy.ruiz@navy.mil	Principal Investigator
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Suzanne O'Hara	Geosyntec Consultants	(519) 822-2230 Ext. 234 Fax: (519) 822-3151 sohara@geosyntec.com	Project Manager
Dr. Jacqueline Quinn	NASA	(321) 867-8410 Fax (321) 867-9161 Jacqueline.W.Quinn@nasa.gov	Technical Advisor and Project Direction at NASA
James Captain	NASA/UCF	(321) 867-8185 lab: (321) 861-3624 fax: (321) 861-2925 James.Captain-l@ksc.nasa.gov	Technical Advisor/Field QA/QC
Dr. Cherie Geiger	UCF	(407)823-2135 Fax(407)823-2252 cgeiger@mail.ucf.edu	Technical Advisor and Project Direction at UCF
Dr. Chris Clausen	UCF	(407)823-2293 Fax(407)823-2252 clausen@mail.ucf.edu	Technical Advisor and Project Direction at UCF