A Brief Description of the Abatement of Lead-Based Paints from Building Components and Potential Consequences of the Persistent Contamination of Lead in These Materials After Abatement

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Prepared By: Jason R. Dorvee, PhD, Associate Technical Director, Research Materials Engineer, United States Army Corps of Engineers, Engineering Research and Development Center, Construction Engineering Research Laboratory

The following document presents a summary of material science-based information pertinent to historic housing and lead contamination that may affect the health, and safety of military families that live in historic housing. With 25,000 historic housing units in the Army portfolio—more than any other federal agency---the presence of lead-based paints in these units is a concern for ongoing management actions such as maintenance, repair, rehabilitation, and renovation. In order to address the health and safety risks to military families from the potential hazards of lead-based paints, this document focuses on providing a review of: the physical and chemical nature of paint as a material, a description of the currently accepted process for lead-based paint abatement, the chemical and physical mechanics of this lead abatement process as it relates to paint as a material, the physical kinetic mechanisms which explain why lead may persist in materials after this abatement process, and finally a description of lead detection techniques (spot test vs X-ray florescence) which may be used before during and after these lead abatement processes, to detect or confirm contamination.

The summation of this report is that all of the current, non-destructive, practices for abatement for lead-based paints found on building components and architectural elements in historic homes poses a probable risk of lead exposure due to the vulnerability of these abatement techniques to allow lead to persist in these materials after the fact. Based on this information, the only means of guaranteeing that the occupants of historic buildings have no exposure to lead within those buildings is to remove the historic elements that contain lead the lead hazard and entirely replace those elements with modern materials that do not contain lead and have never been coated with lead-based paint.

What is Paint?

Paint is composed of four components[1]: pigment, a vehicle/binder, additives, and a thinner/solvent. The pigment is made up of granular solids (e.g. is the lead in “lead-based” paints) that are responsible for the color/dye that is the visible feature of paint that gives it its tint. The vehicle/binder is the organic/polymer component that gives paint its physical characteristics, keeping the pigment suspended when the paint is in liquid form, and then give paint the flexibility, toughness, durability, gloss, and adhesive properties, once the paint dries from a liquid to a solid film. Additives come in many forms but generally play support role as either fillers that toughen the paint (e.g. silica particles), modifiers for surface tension that allow the paint to wet and spread on the surface more evenly; emulsion modifiers that keep the paint from separating into constituent parts; and catalysts that can slow drying, speedup drying (e.g. promote the crosslinking of oil based paints), add UV protection, provide antibacterial characteristics etc. Finally the thinner or solvent is the liquid vehicle for paint, keeping the polymer/organic-binder in liquid form, and is responsible for the viscosity of the paint, giving paint the ability to "flow" so it can be applied to a surface with a brush or spray before the paint dries.

Lead in Paint

The historic roles of lead in paint are as both a pigment and as an additive. For white pigment, granules of white lead, or lead (II) carbonate ($PbCO_3$), are typically used. For a vivid yellow pigment, granules of lead chromate ($PbCrO_4$) are used. Lead pigments are highly opaque, which allows for a little bit of pigment to go a long way in providing a larger coverage area for a relatively small amount of the compound. As an "additive" white lead is highly insoluble in water which makes paint that contains white lead highly water-resistant with both a durable, washable finish. Lead also aids in the drying of oil based paints (promoting oxidation and crosslinking).

Abatement of Lead-Based Paints

Lead as a Hazard

According to the Materials Safety Data Sheet with respect to inhalation and ingestion for While Lead Oil-based Paint:

> Lead is a cumulative poison. Increasing amounts can build up in the body and may reach a point where symptoms and disability can occur. These may include anemia, pale skin, a blue line at the gum margin, decreased hand-grip strength, abdominal pain, severe constipation, nausea, vomiting, and paralysis of the wrist joint. Prolonged exposure may result in kidney damage. If the nervous system is affected, usually due to very high exposures, the resulting effects include severe headaches, convulsions, delirium, coma, and possibly death. Continuous exposure may result in decreased fertility. Elevated lead exposure of either parent before pregnancy may increase the chances of miscarriage or birth defects. Exposure of the mother during pregnancy may cause birth defects.[2]

These warnings and toxicity levels listed in the MSDS are for adults, but only a tiny amount of lead is needed to harm a young, growing child. For children, exposure to lead poisoning can cause problems with their growth, behavior, and ability to learn.[3]

Paint as a material can be removed from surfaces through scraping, sanding, and heat treatment to physically break up the binder component at the bulk level, or it can be removed chemically through the application of solvent or stripping agent that acts as a thinner to loosen or dissolve the binder component at the molecular level. All paint removal methods leave behind some residues of paint embedded in the substrate, which could continue to pose a hazard in the case of lead-based paint if the surface from which the paint is removed is later disturbed. Thus there is a recognized qualifier in the table on page 5 which uses the term "largely removed" with respect to "lead presence" under abatement techniques that focus on removing the paint as opposed to removing the building component entirely.

Lead can be highly toxic in small amounts, and lead hazard thresholds are set with regard to how much of these small amounts of lead exist per unit area of space. Under the 2019 dust-lead hazard standards, lead is considered a hazard when equal to or exceeding 10 micrograms (µg) of lead in dust per square foot (or 0.01 µg/cm^2) on floors, 100 µg of lead in dust per square foot on interior window sills (or 1.0 µg/cm^2).[4] According to the Consumer Products Safety Commission (1977) and (42 U.S.C. 4822(c) painted walls components should be considered "lead-free" when they are visually free of residual paint and there is less than 1 milligram (mg) per square centimeter (1.0 mg/cm^2), lead as measured by X-ray Fluorescence (XRF). As a result of the toxicity of lead-based paint materials, the Occupational Safety and Health Administration (OSHA) recommends the used of personal protective equipment during handling, to include the use of: gloves (rubber or leather), cotton or Tyvek coveralls, chemical/safety impact goggles, and respiratory equipment that vary based on expected exposure levels from 0.5 mg/m^3 to greater than 100 mg/m^3, and best practices where the creation of dust should be avoided where possible.[5]

Enclosure/Stabilization of the Paint

The greatest risk of exposure to dust and fragments of lead-based paint comes from either abrasion of the paint through wear or weathering or through the direct consumption of the paint through gnawing of the material and chipping of the paint by children playing with painted surfaces. In cases where paint is likely to crack or chip via weathering, encapsulation or stabilization of the paint surface is the recommend form of remediation irrespective of initial paint condition. These techniques involve coating the painted surfaces directly with an additional sealant and should not be confused with "enclosure". Enclosure is the installation of a rigid, durable barrier that is mechanically attached to building components, with all edges and seams sealed with caulk or other sealant.[6] The primary cost driver for both encapsulation and paint stabilization is the proper surface preparation in order for either technology to perform as intended. Any and all substrate damage must also be repaired. This technique does not remove the lead, it only mitigates its release into the environment. These solutions have a limited life cycle of no more than 20 years and professional independent reevaluations may be required at 2-year intervals.[7] Encapsulation and stabilization of the paint does not guard against the potential risk of lead hazard control failure in areas of the home that are prone to wear via repetitive mechanical use such as steps, flooring, cabinets and windows.

Mechanical/Abrasive Removal of paint

In lieu of encapsulation or stabilization, mechanical removal of lead-based paint from surfaces requires sanding or scraping the surface, which can gouge relatively soft substrates such as drywall and plaster resulting in a poor appearance and additional cost to repair or replace the original material. Heat guns can be used to blister the paint from wood, metal or ceramic surfaces (not plastic, or papered [drywall]) to make it easier to mechanically remove paint without heavy scraping, but the heat output of these guns range in temperatures between 112° F and 1112° F and require training and experience to use appropriately. Aside from the fact that heat guns present a possible fire hazard, the use of heat could result in the decomposition of lead(II) carbonate at 600°F[8] and may result in vaporizing the lead and introducing a new potential inhalation hazard; making proper removal with this technique expensive.

Chemical Removal: On site

Chemically, lead-based paints can be removed on-site using a membrane stripping technique, which has been found to be generally effective at removing paint and reducing the lead hazard, but not eliminating it altogether.[9] This technique involves coating the painted surface with a chemical paste and then applying a plasticized membrane film over the paste. After a period of time, the chemical paste reacts with the paint, loosens/dissolves the binder at the molecular level, and binds the paint to the membrane film. Peeling back the film removed the paint directly and encapsulates the paint-film (that has been removed) in the membrane. Membrane chemical stripping will not remove 100% of the paint in a single application---as determined by lead concentration assessment criteria-- as confirmed using both visual inspection and XRF analysis.[10]

In addition of needing multiple applications of the membrane film method to remove the paint, for plaster surfaces removal of residual paint and lead contamination must be accomplished by additional stripper applications or by HEPA sanding (dust is captured using specialized vacuuming techniques). The membrane film technique works best with flat untextured surfaces with a minimal amount of grooves and crevasses. Ultimately, significant amounts of patching and repair are necessary to improve the final appearance

Table: Comparison of Lead-Based Paint Abatement, Component Removal and Enclosure[11]

	Abatement and Removal						Enclosure			
Attributes	HEPA Needle Gun	Heat Gun	HEPA Sanding	Remove/ Replace	Caustic Paste/ Solvent	Off-site Stripping	Plywood Paneling	Gypsum	Prefab Metal	Wood, Metal, Vinyl Siding
Skill Level	High	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	Moderate
Aesthetics (1)	Erodes surface	Gouges	Gouges/ roughens	Good	Gouges	Good	Good	Good	Good	Good
Applicability	Very low, limited to metal and masonry	Wide, can damage some components	Low, limited by surface contour	Wide, dependent on skill	Wide, can damage some components	Low, components only	Wide, walls	Wide, walls and ceilings	Varied, limited by components	Wide, walls
Lead Presence	**Largely removed**	**Largely remove**	**Largely remove**	**Removed**	**Largely remove**	**Largely removed**	**Remains**	**Remains**	**Remains**	**Remains**
Generation of Hazardous Waste (2)	Low to moderate	Low to moderate	Low to moderate	Low	High	High, but maintained off-site	Low	Low	Low	Low
Weather Limitations	Moderate	High	Moderate	Minimal	High	None	Minimal	Minimal	Minimal	Minimal
Applicable to Friction Surface	Some	Yes	Some	Yes	Yes	Yes	No	No	Yes	No
Surface Speed of Methodology	Slow	Slow	Slow	Moderate	Slow	Can be slow, requires coordination	Moderate	Moderate	Moderate	Moderate
Training Required	High	Moderate	Moderate	High	Moderate	Moderate	High	High	High	High
Capital Required	High	Low	Moderate	Moderate	Low	Low	Low	Low	High	Moderate
Worker Protection Required (3)	High	High	High	Moderate	High	Moderate	Low	Moderate	Low	Low
Finish Work Required	Tentatively	Moderate	Moderate	Low	Moderate	Moderate	Wide	Wide	Limited	Wide
Product Availability	Limited	Moderate	Limited	Wide	Moderate	Limited	Moderate	Moderate	Wide	Wide
Durability	Long	Long	Long	Long	Long	Long	Moderate	Moderate	Moderate	Moderate
Labor Intensity	High	High	High	High	High	Moderate	High	High	High	High
Overall Safety (3)	Moderate	Moderate	Moderate	Very high	Moderate	High	High	High	High	High
Surface Preparation	None	None	None	None	Minimal-adjacent areas	Minimal-hardware removal	Minimal	Minimal	Minimal	Minimal
Cost	High	High	High	High	High	High	Moderate	Moderate	High	Moderate

Notes (1) – The degree of damage to the surface will depend on the expertise of the operator.

(2)– Concentrated lead-based paint waste or sludges from paint removal using caustic or organic solvent removers have to be TCLP tested to determine if they are hazardous waste. See Chapter 10.

(3)– Any construction work involves increased safety risks.

of surfaces prepared by chemical membrane paint removal and result an additional cost during repainting. The quantity of hazardous waste produced by the process is significant and requires added cost of waste disposal.

Chemical Removal: Off-site

For painted areas of the home that cannot be: stabilized, encapsulated, or prepared using a membrane stripping technique, chemical stripping can be performed off-site. Moving building components, such as windows, off-site protects the site from lead contamination and allows for access to all of the painted surfaces of the window for chemical striping. As a result, this one of the most accepted processes for the removal of paint from historic materials in an effort to keep the original material of the building component and not discarding it completely (termed “Largely removed” in the above table). This process can be performed using chemicals as part of wet stripping (solvent or caustic solution plus mechanical scraping), membrane film stripping, all followed by repeated rinsing.

Dip Stripping

Detachable wood elements such as windows can also be "dip-stripped. In general, this process is left to professional companies because caustic solutions used to break apart the paint binder can also dissolve skin and permanently damage eyes. The waste generated from this process can also pose serious disposal problems in large quantities.[12] Dip stripping---as a form of chemical stripping---involves placing the building component in a large vat of solvent or caustic solution to assure that all of the painted surfaces are coated with the solution. Components can be left in these vats for several days to guarantee that the solvent/solution permeates all the layers of paint/varnish.

After the window/building components has been treated by anyone of the above off-site chemical removal techniques it is rinsed, dried, and repainted (with non-lead-based paint) it is then returned to the site of renovation and re-installed.

Kinetics of paint striping and the diffusion of lead in wood

As discussed earlier, solvent and thinners work to break apart the binder component at the molecular level effectively dissolving the material that binds together all of the other respective components of paint (i.e. pigments and additives). As the granules of the lead-based pigment in the paint become solvated and separates from rest of the components these lead-based granules are suspend in the solution and move with this liquid phase. This leftover lead-laden solution is subsequently free to soak into the pores and cracks of a surface of the building component---especially wood. If the lead-based pigment moves with the binder it can harden into the pores when the component dries effective “repainting” this part of the wood with the original lead-based paint, otherwise the lead simple sits in the pores and cracks.[13]

In the case of “dip stripping” as described in the previous section, it is not economically feasible to change the solution of these vats after the treatment of each individual building component for stripping; so naturally, overtime these vats accumulate greater and greater concentrations of contaminants in the solution from each success lead-based painted building component that is placed in the vat. From a paint removal perspective, this system is very efficient but the probability of secondary contamination of the stripped wood grows with exposure time to the solution and with each successive building component that is placed in the vat to be stripped. During the paint-dissolution process, the concentration lead-pigments granules released into solution gradually increases. As the concentration of these free-lead contaminates rises in the vat from each stripping the subsequent persistence of the bare wood material in the solution leads to a greater and greater driving force for the diffusion of the lead contaminants into the exposed wood, allowing the lead contamination to saturate and permeate the pores and cracks of the wood over time.[14] More stripping and more time in the vats mean greater and more persistent secondary lead contamination of the wood.

Release of lead back into the environment.

After the building component is repainted, any leftover lead on the surface of the wood will mix with the new non-lead-based paint, while lead that has diffused deeper into the wood will simply become encapsulated by the new paint. When the window is dried and re-installed, it will still contain some amount of moisture that it absorbed during the wet stripping process. This moisture will move around within the wood with changes in temperature and humidity (causing the wood to swell and shrink with the weather). Additionally, as water moves into and out of the wood through the absorption and evaporation of atmospheric water, the lead that had diffused into the wood during the abatement process and had become trapped after the repainting will now begin to move with the water and migrate to the interface of the wood, stopping at the newly painted surface. Overtime repeated use and operation of the window will lead to wear and abrasion of the paint. When the new paint chalks, chips, or peels, under normal wear, the contamination that had mixed with the new paint and the trapped lead---that had diffused through the component with swelling of the wood-- will once again be released.[15] This scenario illustrates how a building component that may have been treated for lead removal and found to be “lead-free” can become a ready source of lead contamination under normal use and operation after the fact.

Detection of lead

As articulated earlier, lead-based paint as a cured, undamaged film does not in-of-itself present a hazard. It is the chips, and dust from lead-based paint that is the health hazard. It is important to point out once again that stripped walls and ceilings should be considered "lead-free" when the lead concentration is less than 1 mg/cm^2, this condition is also true for newly painted surfaces under 42 U.S.C. 4822(c), but does not apply to dust or chips that would come off these surfaces. Under the 2019 dust-lead hazard standards, lead is dust and chips are considered a hazard when the concentration of lead is equal-to or exceeding 10 μg of lead in dust per square foot (or 0.01$\mu g/cm^2$) on floors, 100 μg of lead in dust per square foot on interior window sills (or 1.0$\mu g/cm^2$).[16] These are the concentrations and regulations by which lead hazards are measured for both painted surfaces and dust respectively. A painted surface that has the same concentration of lead equal to the hazard-level threshold for dust would **NOT** be consider hazardous, but dust that has the same concentration of lead equal to the "lead-free" threshold allowed for a painted surface **WOULD** be considered a hazard.

Spot tests

A common field test for lead (other than visual inspection) is a spot test. These spot tests are commercially available as "lead paint test kits" and must meet EPA performance standards. The clear criteria set by the EPA-regulated lead level for paint— is equivalent to 0.5 percent of the paint's formulation (0.087 mg/cm^2)[17] by weight and the kit must accurately produce a positive or negative result 95 percent of the time (in other words only fails 1 out of 20 times). Spot tests are 19th century technology first published in 1859.[18] Chemical spot test kits, quite simply detect the presence of lead in paint by chemical reactions that occur when chemicals in the kit are exposed to lead, causing a color change to occur if lead is present. According to the EPA, there are two types of kits: rhodizonate kits and sodium sulfide kits. Rhodizonate kits indicate the presence of lead by turning red or pink. Sodium sulfide kits indicate the presence of lead by turning black or grey.[19] Spot tests are based on reactivity of chemical species, require significant quantities of material, and can be prone to both false positives and contamination. Certain elements in paint or the material below the paint, such as sulfates in plaster, may interfere with the functioning of a kit. Therefore spot tests cannot determine whether or not lead has been completely removed from the environment but they can indicate whether or not the amount of lead present is above or below the consideration of a "lead-free" environment as determined by the Consumer Products Safety Commission (1977) and [42 U.S.C. 4822(c)].

Given the limitation of spot tests---which by EPA standards require concentrations of lead greater than 1000-fold the 2019 dust-lead hazard standards (0.01$\mu g/cm^2$ for floors) in order to be effective---these tests are not useful at measuring lead exposure once the lead has chipped from the window or has become dust.

What does this mean?

If a building component such as a historic window from a historic home which had been previously painted with lead based paint (standard concentration at the time was 50% lead by weight), is then stripped using a chemical-based technique at an off-site location as to not contaminate the site, and regardless of whatever technique was used the stripped component is left with only a residual concentration of lead equal to 0.085 mg/cm^2 --- a concentration that is below the 42 U.S.C. 4822(c) threshold of 1 mg/cm^2 and below the detection limit of a commercial spot test as regulated by the EPA---then this window would be considered “lead-free”. As a “lead-free” material, this window would be repainted with a modern latex “lead-free” paint —, which as stated previously would likely bond-with or trap the lead contamination within the window. Once this window is freshly painted, it would likely be tested again and be found to be “lead-free” by the same EPA regulated spot test.

After abatement and re-installation, this window would be consider–by the 42 U.S.C. 4822(c) “lead-free”--however once this remediated window is put to regular use and operation, there is a potential for the newly painted surface to chip or wear from the friction of these painted surfaces moving against each other. Bear in mind, the painted surfaces in this scenario are still contaminated with lead but only at an effective concentration of 0.085 mg/cm^2---below the 1 mg/cm^2 threshold. If the abrasion of this low contaminated paint results in the release of particulates no bigger than a 1 mm in length (100 μm^2), then at these concentrations this single 1 mm particle occupying a 1 cm^2 area of the windowsill would be considered a lead hazard and **NOT** “lead-free” according to the 2019 dust-lead hazard standards of window sills. Worse yet, this single particle would be considered 100 times the concentration threshold of what is considered toxic for the presence of lead dust on floors. To think of this in another way, if the abrasion of the window sash was so fine as to produce particles that are 100 times smaller than this one we (making them no thicker than a human hair) and these particles were to fall from the window sill on to the floor they would be considered a lead hazard, despite the fact that the window that they came from would be considered “lead-free” by 42 U.S.C. 4822(c) and the corresponding EPA regulation. In this scenario, the window may be “lead-free” but the dust that comes off of it is not, and continues to present a potential lead hazard to building occupants.

X-Ray Fluorescence Spectroscopy

The scenario illustrated above highlights the importance for accurate, high-resolution techniques to characterize lead concentrations in the field. X-Ray Fluorescence Spectroscopy (XRF) is one such technique used for characterization of lead contaminants in the field. XRF is a 20th century a non-destructive analytical technique used to determine the elemental composition of materials. In short: During the analysis, a material of interest is subjected to X-rays of a particular wavelength (in other words a unique "color" within the X-ray spectrum) which excites the elements of the material to produce secondary X-rays (Fluorescent X-rays of a different color). This is very similar to the visual effect of shinning a UV-based black light on a neon sign or fabric, causing the fabric to luminesce brightly in the in visible spectrum. The set of secondary X-rays are characteristically unique ("an atomic fingerprint") to specific elements, thus this technique can be used for both qualitative and quantitative measurements of small amounts of specific elements. Handheld XRF analyzers can have detection levels as low as 10 µg[20]; this translates to a lower limit of detection being no less than 10 of the 1 mm lead-contaminated particulates from the scenario that was outlined previously. Field tests are performed using dust wipes to swab the area of interest, follow by analysis of the dust wipe using a handheld analyzer to produce results immediately for the user. Although these analyzers do not detect concentrations below 10 µg, the ability to swab an area allows for a representative sample of the contamination to be analyzed for the lead-based health hazard that is a cumulative poison and this technique is of a significantly higher resolution than a commercial spot test.[21]

Summary

In summary, the current practice of abatement of lead-based paint to bring building components to a state of "lead-free" is not truly free of lead, and the wear or chipping of paint from these refurbished building components still presents a risk of exposure to lead-borne dust/debris at concentrations greater than the 2019 dust-lead hazard standards. These rehabilitated historic building components and architectural elements still pose a probable risk of lead exposure due to the susceptibility of these abatement techniques to allow lead to persist in these components after the fact. As illustrated from the attached table reproduced from the HUD 2012 report[22], the only way the potential lead hazard can be completely removed from historic housing is to remove and replace the architectural element or building component (e.g. window, door, cabinet) that is contaminated with lead-based paint. Given the absence of lead-based paint & materials when using modern replacement materials, the risk of introducing lead exposure with these new materials in non-existent.

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[7] Lead Abatement for Workers, Student, Chapter 7: Abatement Methods, EPA 2017-02
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[9] ERDC/CERL TR-03-30, Technology Demonstration of Membrane Chemical Strippers for Removal of Lead-Based Paint on Plaster, December 2003
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[11] Reproduced from Table 12-2 of the U.S. Department of Housing and Urban Development Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing, Second Edition, July 2012
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[15] Lead Abatement for Workers, Student, Chapter 7: Abatement Methods, EPA 2017-02
[16] Hazard Standards for Lead in Paint, Dust and Soil (TSCA Section 403), EPA https://www.epa.gov/lead/hazard-standards-lead-paint-dust-and-soil-tsca-section-403
[17] Average Density of latex house paint = 1.34 g /cm^3; 0.05% of house paint = 6.7 mg/cm^3; average thickness of a coat of paint is 4-5 MILS = 0.013 cm; a 0.05% amount of a coat of house paint is 0.013cm x 6.7 mg/cm^3 = 0.087mg/cm^2
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Army Points of Contact:

Jason R. Dorvee, Ph.D. - jason.r.dorvee.civ@mail.mil

David Guldenzopf, Ph.D. - david.b.guldenzopf.civ@mail.mil