

# Health and Safety Concerns Relating to Lead and Lead Compounds in Conservation

Lyndsie Selwyn

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## Health and Safety Concerns Relating to Lead and Lead Compounds in Conservation

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*The purpose of this paper is to raise awareness of the health hazards of lead, its alloys and compounds, as they are among the most hazardous materials found in association with cultural property and are often encountered by conservators in the course of treatments. Lead toxicity is described and a general survey is presented of the types of objects or materials where lead might be encountered in cultural heritage sites and institutions. When dealing with lead-containing materials, conservators, as well as all others who treat, handle or dispose of lead, need to follow the relevant occupational and environmental laws. In Canada, applicable occupational health and safety laws depend on where one lives and for whom one works. Resources, including current websites, are provided for locating the federal, provincial, and territorial legislation as well as some provincial lead guidelines relating to exposure limits, and environmental and medical monitoring. General information is given for engineering controls (isolation, ventilation), administrative controls (personal hygiene, housekeeping, storage and disposal of hazardous waste), and personal protective equipment (respirators and protective clothing). Guidelines are provided for conservators working with lead-containing objects or lead-based pigments on painted surfaces so that they can recognize lead and lead corrosion and protect themselves, those working around them, and their families at home from lead poisoning. Analytical methods for the detection of lead in paint, including spot tests, are briefly described.*

*Le but de cet article est de sensibiliser le lecteur aux risques pour la santé que présentent le plomb, ses alliages et ses composés. En effet, le plomb et ses dérivés sont parmi les substances les plus toxiques qu'on retrouve sur des oeuvres d'art et autres biens culturels, et il n'est pas rare qu'un restaurateur les croise lors de traitements. L'article décrit la toxicité du plomb ainsi que les différents types d'objets et de matériaux risquant d'en contenir qui se retrouvent souvent dans les collections muséales ou dans celles des sites historiques. Lorsqu'on doit s'occuper d'objets contenant du plomb, par exemple si on a à les manipuler, les traiter ou s'en débarrasser, il est nécessaire de suivre la réglementation en matière de santé et sécurité au travail ainsi que les lois environnementales. Au Canada, différents règlements sur la santé et la sécurité au travail s'appliquent selon les provinces, l'endroit où l'on habite, et aussi l'employeur. L'article fournit des ressources utiles, par exemple des adresses de sites web, afin d'aider le lecteur à accéder à la réglementation fédérale, provinciale ou territoriale qui s'applique à sa situation précise. Des lignes directrices émises par diverses provinces sont aussi présentées concernant les limites d'exposition et les suivis du côté médical et environnemental. Des renseignements généraux sont donnés sur diverses mesures de contrôle, tant au niveau de l'édifice (recours à des enceintes d'isolement, ventilation) qu'au niveau de la gestion (mesures d'hygiène personnelle, d'entretien ménager, de stockage et d'élimination de produits dangereux) et de la protection personnelle (respirateurs, vêtements protecteurs). Enfin, on fournit des lignes directrices pour le restaurateur ayant à travailler avec des objets contenant du plomb ou sur des couches picturales contenant des pigments à base de plomb, dans le but de l'aider à reconnaître la présence du plomb ou de produits de corrosion qui en dérivent, et aussi de non seulement mieux se protéger personnellement, mais aussi, de protéger ses collègues de travail et les membres de sa famille qui pourraient eux aussi être indirectement exposés. Des méthodes d'analyse permettant d'identifier la présence de plomb dans la peinture, et entre autres des tests ponctuels, sont aussi brièvement décrits.*

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### Introduction

Lead is one of the oldest known metals, used well before 3000 B.C.<sup>1-3</sup> It was not difficult to extract lead from ores using wood fires, and lead was easy to cast because of its low melting point (327°C). Early civilizations used lead extensively for plumbing, building, and ship construction. Lead was also used for stationery, fashioning ornaments (figurines and bracelets, for example) and for the manufacture of such items as standard weights, solders, and rivets to repair pottery. In ancient Greek and Roman times, syrups called *sapa* or *defrutum* (contaminated with lead acetate trihydrate, also called sugar of lead because of the sweet taste) were used to sweeten wine and food, and to inhibit spoilage. These syrups were prepared by boiling grape juice in lead-lined pots until the desired thickness was achieved.

The toxic potential of lead has been known since antiquity, with warnings about its hazards dating at least as far back as the second century B.C.<sup>4</sup> Concerns about lead toxicity, especially as

this affects children, have since limited or eliminated many applications. Despite concerns about poisoning, lead metal is still used for a variety of purposes, and is found in roofing, storage batteries, solders, ammunition, stained glass windows, and radiation shields. Lead compounds continue to be used as pigments (in limited quantities for artistic paints and craft products), in crystal, plastics, insecticides, and as additives to high-pressure lubricants.

In museums and other cultural heritage institutions, lead can be found in many objects because of its widespread use in the past. This paper is relevant to conservators who, on occasion, work on these lead-containing objects, because there is a risk of developing lead poisoning, as demonstrated by several examples.<sup>5-9</sup> Risk of exposure to lead occurs, for example, when conservators remove lead-based paint finishes from polychrome sculptures, historic buildings, or industrial sites; conserve paintings or painted surfaces (with lead compounds present in pigments, grounds, patches, and adhesives); disassemble and

restore stained glass windows; work on lead sculptures (or leaded bronze sculptures) or small lead toys (e.g. toy soldiers) covered with corrosion or leaded paint; cast, braze, tin or solder with lead-containing alloys; or many other conservation tasks.

The main purpose of this paper is to raise awareness about the health hazards associated with lead, to provide information about minimizing occupational exposure during treatments, and to provide resources for locating guidelines and federal, provincial or territorial legislation relevant to working with or to the disposal of lead. **Table I** lists websites for organizations where a range of information about lead can be found; some are particularly useful for keeping up-to-date on regulations.

### Lead Toxicity

Lead is one of the most hazardous toxic metals because the poison is cumulative, and its toxic effects are many and severe.<sup>10</sup> Virtually no part of the body is immune from the effects of lead. On an atomic level, lead has no biological value but it competes with metals that are essential to the human body, such as zinc, iron and calcium.<sup>11</sup> The American Conference of Governmental Industrial Hygienists (ACGIH)<sup>12</sup> categorizes lead and inorganic lead compounds as A3 (confirmed animal carcinogens with unknown relevance to humans). However, in January of 2005, lead and lead compounds were declared to be “reasonably anticipated to be human carcinogens” by the National Toxicology Program in the United States.<sup>13</sup>

Prolonged absorption of lead or its compounds can cause the onset of lead poisoning (also known as plumbism or saturnism). Acute exposure (high-level exposure over a short time) can cause colic, convulsions, coma and death, whereas chronic exposure (low-level exposure over a long time) can cause anaemia and damage the brain, nervous system, digestive system, and kidneys.<sup>14</sup> Lead is also capable of interfering with both female and male reproductive systems. Children (and the developing fetus) are more seriously affected by lead than adults.<sup>10</sup>

The health impact of lead is determined primarily by the amount of lead that enters and is retained in the body, and this is largely determined by the physical form of the lead rather than its chemical form.<sup>15</sup> Lead may enter the body by absorption through the skin, by inhalation into the lungs, or by ingestion.<sup>14</sup> The more dangerous physical forms are lead-containing dusts, fumes, mists, and liquids (particularly organic lead compounds) and their vapours because in these forms lead is more readily absorbed into the body. The main occupational route of entry of lead contamination is inhalation of fine dust or fumes.

Lead dusts are formed when solid materials are broken down into small particles by natural or mechanical forces. Dusts can be created, for example, when handling lead-containing compounds or when grinding, sanding, polishing or cutting lead or lead-containing materials. The dust can vary in size from large particles (which tend to drop to the ground) to fine particles (which can remain airborne for long periods of time).

**Table I: Websites Relating to Lead-containing Materials, Regulations, Analysis and Health and Safety.**

American Conference of Governmental Industrial Hygienists (ACGIH)	< <a href="http://www.acgih.org">http://www.acgih.org</a> >
American Industrial Hygiene Association (AIHA)	< <a href="http://www.aiha.org">http://www.aiha.org</a> >
Canada Mortgage and Housing Corporation (CMHC)	< <a href="http://www.cmhc-schl.gc.ca">http://www.cmhc-schl.gc.ca</a> >
Canada's National Occupational Health and Safety Website	< <a href="http://www.canoshweb.org">http://www.canoshweb.org</a> >
Canadian Association for Environmental Analytical Laboratories	< <a href="http://www.caeal.ca">http://www.caeal.ca</a> >
Canadian Centre for Occupational Health and Safety (CCOHS)	< <a href="http://www.ccohs.ca">http://www.ccohs.ca</a> >
Canadian Paint Association	< <a href="http://www.cdnpaint.org">http://www.cdnpaint.org</a> >
Canadian Standards Association	< <a href="http://www.csa.ca">http://www.csa.ca</a> >
Department of Justice Canada	< <a href="http://www.canada.justice.gc.ca">http://www.canada.justice.gc.ca</a> >
Health Canada	< <a href="http://www.hc-sc.gc.ca">http://www.hc-sc.gc.ca</a> >
International Lead Management Center	< <a href="http://www.ilmc.org">http://www.ilmc.org</a> >
National Institute for Occupational Safety and Health (NIOSH)	< <a href="http://www.cdc.gov/niosh">http://www.cdc.gov/niosh</a> >
Standards Council of Canada	< <a href="http://www.scc.ca">http://www.scc.ca</a> >
U.S. Department of Housing and Urban Development (HUD)	< <a href="http://www.hud.gov">http://www.hud.gov</a> >

Lead fumes are extremely fine particles created after lead or lead-containing alloys have been heated to a temperature high enough to vaporize the lead, which then reacts with oxygen and condenses into fine lead oxide particles.<sup>14,16</sup> The heating process may involve casting, soldering, brazing, welding, tinning, laser cleaning, or lead burning. The plume of smoke generated during soldering can contain metal fumes and a variety of decomposition products from materials in fluxes that can cause eye and respiratory irritation.<sup>14</sup> Electric soldering irons operating below 500°C do not generate significant lead fumes; however, higher temperatures vaporize more metal and heating processes above 500°C do generate appreciable amounts.<sup>17</sup> Lead fumes can also be generated by heating metal that has been painted with a lead-based coating, or by burning candles if a lead core has been used to stiffen the wick.<sup>18</sup> (In Canada, lead content in consumer products is regulated by Health Canada under the *Hazardous Products Act (HPA)*.<sup>19,20</sup> Health Canada is currently drafting *Candle Regulations* under the *HPA* to prohibit the import, advertisement or sale of candles in Canada which contain more than 600 mg/kg total lead in the wick or anywhere else in the candle.<sup>21</sup>)

Mists are tiny liquid droplets in the air. Lead can be inhaled when mists are generated – for example, during spray painting with products containing lead compounds.

In general, the smaller the size of the dust, fume or mist particles, the longer they remain airborne. Eventually, they settle in the work space, in ventilation ducts, in hair or clothing, or wherever air currents carry them. Furthermore, the smaller the particle size, the deeper they can be inhaled, and the more toxic they are liable to be because they can be absorbed more efficiently.<sup>16</sup> Fine “respirable” dusts (0.5-10 µm) and fumes (0.01-0.5 µm) are invisible to the eye and are especially dangerous because when inhaled they can penetrate deep into the lung.<sup>14,22</sup>

When lead is swallowed, it is absorbed into the bloodstream through the digestive tract (adults absorb about 10% of ingested lead); when lead is inhaled, it is absorbed through the respiratory tract (adults absorb about 30-40% of inhaled inorganic lead and 80% of inhaled organic lead).<sup>15,23</sup> Furthermore, it is possible to absorb both inorganic lead compounds (such as lead dust and lead oxides) and organic lead compounds through the skin.<sup>4,15,22,24</sup> Factors that influence the bioavailability of lead (i.e., how much lead is dissolved into the body fluids and absorbed into the blood stream) include the particle size, chemical properties of the lead, and the nutritional status of the person.<sup>4,11</sup> Larger particles and compounds having low aqueous solubility are presumed to be less hazardous than finely divided particles and compounds of higher solubility.<sup>2</sup> Although certain lead compounds are insoluble in water, they may be soluble in lung or digestive fluids because of the complex nature of these fluids, and so it is wise to consider all compounds containing lead as potentially toxic.<sup>14</sup> Dietary deficiencies of calcium, iron, zinc, copper and vitamin D have been shown to enhance lead absorption.<sup>22</sup>

Once lead has been absorbed into the bloodstream, it circulates until it is either stored in the body or excreted. Lead’s

half-life in blood – the time it takes half of a given amount of lead to be removed – is estimated to be in the range of 27 to 36 days.<sup>4,23</sup> The lead is stored primarily in bone (and teeth), and to a lesser degree in the kidneys, liver, spleen and brain.<sup>4,11</sup> It is even deposited in the hair. About 95% of the body lead burden is stored in bone.<sup>23</sup> Lead may be released from the bone back into the blood during pregnancy, illness, stress, or aging. Lead’s half-life in bone exceeds 20 years, possibly being as long as 30 years.<sup>4</sup> Because of the length of time lead remains in bones, even small amounts of lead that have accumulated in the body can cause effects that endure long after exposure ends.

### Recognizing Metallic Lead and Typical Corrosion Products

Lead is a heavy bluish-gray metal which is silvery when freshly cut but darkens on exposure to air. Because lead is soft, objects made from lead are easily scratched and thin pieces of lead bend easily. When a freshly exposed metal surface is rubbed onto white paper, a black mark is left behind. In conservation, the presence of lead is often detected using lead test paper (see **Appendix 1**).<sup>25-27</sup> In x-radiography of objects, metallic lead and its compounds appear relatively opaque, due to the high mass absorption coefficient of lead.

Indoors, historic objects made from lead gradually develop a stable, dark patina. Lead objects that have been buried or exposed outdoors become covered with an adherent film of relatively insoluble lead compounds.<sup>28-30</sup> Lead compounds formed outdoors are not completely insoluble; depending on the pH and composition of rain, a certain amount of lead can dissolve and contaminate the nearby environment.<sup>31</sup> More information on the corrosion of lead indoors, outdoors, and during burial is available elsewhere.<sup>32</sup> The lead-based corrosion products formed in any environment are a potential source of lead poisoning during handling or conservation treatment. **Table II** contains information about selected lead compounds or minerals mentioned in the paper, and is provided as a guide to the reader.

Lead metal is susceptible to corrosion indoors when the local environment (for instance, within a display case) is contaminated with volatile organic acids such as acetic acid (the acid in vinegar). As the metal corrodes, the dark patina is usually replaced by white powdery corrosion products. Sources of these organic acid contaminants are usually wood (with oak and cedar being the worst), wood products, oil-based paints, some emulsion paints, and certain adhesives.<sup>33</sup> Lead objects will continue to corrode as long as they remain in an environment with sufficient levels of acid and moisture. **Figures 1** and **2** show an example of active corrosion on lead came surrounding the glass in a stained glass artifact that had been stored in a closed wooden cabinet.

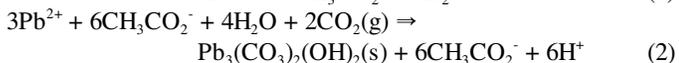
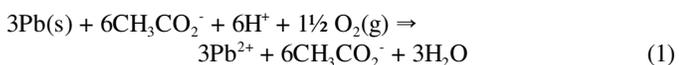
The formation of white corrosion products on lead exposed to acetic acid results from the initial formation of soluble lead acetate. The following corrosion cycle is thought to occur on lead (Pb), given sufficient moisture to form a layer of water on the surface and acetic acid (CH<sub>3</sub>CO<sub>2</sub>H) and oxygen to dissolve in the water layer:<sup>34</sup>

**Table II: Selected Lead Compounds.**

Chemical Name	Chemical Formula	Mineral Name	Selected Common Names	Colour
<b>Oxides</b>				
Lead(II) hydroxide	Pb(OH) <sub>2</sub>			white
Lead(II) oxide	α-PbO	litharge	lead monoxide	red
Lead(II) oxide	β-PbO	massicot	yellow lead, lead monoxide	yellow
Lead(II, IV) oxide	Pb <sub>2</sub> O <sub>3</sub>		lead sesquioxide, lead trioxide	orange-yellow
Lead(II, IV) oxide	Pb <sub>3</sub> O <sub>4</sub>	minium	red lead, orange lead, lead tetroxide	bright orange-red
Lead(IV) oxide	PbO <sub>2</sub>	plattnerite	lead peroxide, lead brown, lead dioxide	dark brown
<b>Carbonates</b>				
Lead(II) carbonate	PbCO <sub>3</sub>	cerussite	normal (neutral) lead carbonate	white
Lead(II) carbonate hydroxide	Pb <sub>3</sub> (CO <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub>	hydrocerussite	white lead, basic lead carbonate	white
<b>Chlorides</b>				
Lead(II) chloride	PbCl <sub>2</sub>	cotunnite		white
Lead(II) chloride hydroxide	PbClOH	laurionite	basic lead chloride	white
Lead(II) chloride oxide	Pb <sub>7</sub> Cl <sub>2</sub> O <sub>6</sub>	lorettoite	lead oxychloride	yellow
<b>Sulphates</b>				
Lead(II) sulphate	PbSO <sub>4</sub>	anglesite		white
Lead(II) oxide sulphate	Pb <sub>2</sub> OSO <sub>4</sub>	lanarkite	basic lead sulphate	white
<b>Sulphide</b>				
Lead(II) sulphide	PbS	galena	lead glance	black
<b>Organics</b>				
Lead(II) acetate anhydride	Pb(CH <sub>3</sub> CO <sub>2</sub> ) <sub>2</sub>		anhydrous lead acetate	white
Lead(II) acetate trihydrate	Pb(CH <sub>3</sub> CO <sub>2</sub> ) <sub>2</sub> •3H <sub>2</sub> O		normal (neutral) lead acetate, sugar of lead	white
Lead(II) acetate hydroxide	Pb <sub>3</sub> (CH <sub>3</sub> CO <sub>2</sub> ) <sub>2</sub> (OH) <sub>4</sub>		basic lead acetate, lead subacetate	white
Lead(II) formate	Pb(HCO <sub>2</sub> ) <sub>2</sub>			white
Lead(II) oleate	Pb(C <sub>18</sub> H <sub>33</sub> O <sub>2</sub> ) <sub>2</sub>			
Lead(II) stearate	Pb(C <sub>18</sub> H <sub>35</sub> O <sub>2</sub> ) <sub>2</sub>			
Tetraethyl lead	Pb(CH <sub>2</sub> CH <sub>3</sub> ) <sub>4</sub>			
Tetramethyl lead	Pb(CH <sub>3</sub> ) <sub>4</sub>			
<b>Miscellaneous</b>				
Lead(II) antimony oxide	Pb <sub>2</sub> Sb <sub>2</sub> O <sub>7</sub>	bindheimite	lead antimonate, Naples yellow	yellow-orange
Lead(II) chromium oxide	PbCrO <sub>4</sub>	crocoite	lead chromate, chrome yellow	yellow
Lead(II) chromium oxide	Pb <sub>2</sub> CrO <sub>5</sub>	phoenicochroite	basic lead chromate, chrome red, chrome orange	dark orange
Lead(II) cyanamide	PbCN <sub>2</sub>			yellow
Lead(II) phosphate	Pb <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>		lead orthophosphate, trilead phosphate	white
Lead(II) silicate	Pb <sub>3</sub> Si <sub>2</sub> O <sub>7</sub>		lead pyrosilicate	yellow
Lead(II) tin oxide	Pb <sub>2</sub> SnO <sub>4</sub>		lead tin yellow, lead stannate	greenish yellow
Lead(II) titanium oxide	PbTiO <sub>3</sub>	macedonite	lead metatitanate, lead titanate	yellow-brown



**Figure 1.** This stained glass angel was stored in a closed wooden cabinet; the lead came surrounding the glass is suffering from active corrosion, and has turned white. Photograph courtesy of the Canadian Conservation Institute.



where (s) refers to solid, and (g) refers to gas. As the lead corrodes in reaction (1), the lead ions generated at the metal surface dissolve in the surface water and react with acetic acid to form soluble lead acetate which diffuses away. In reaction (2), the lead acetate solution absorbs atmospheric carbon dioxide and precipitates white corrosion products comprising mainly lead carbonate hydroxide ( $\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$ ).

The loosely-adherent and powdery white lead corrosion products are a potential source of lead-contaminated dust. White corrosion products (mainly lead carbonate hydroxide) are often encountered on lead inside display cases (e.g., lead anchors on wooden ship models), on stained glass windows where contaminated rainwater has collected, and on the underside of lead roofs (a corrosion process known as underside corrosion<sup>35,36</sup>). Active lead corrosion has even been observed on objects made from leaded copper alloys.<sup>37</sup> Another corrosion product, lead formate, can develop in the presence of formic



**Figure 2.** A close-up of a soft solder join in the stained glass angel pictured in Figure 1, which shows that the solder is not corroding. It is probably a lead-tin alloy with sufficient tin to make it more resistant to active corrosion than the adjacent lead came. Photograph courtesy of the Canadian Conservation Institute.

acid. Gray crystals on the wheel of a toy chicken (see **Figure 3**) on exhibit for 9 years in a sealed display case at the Glenbow Museum were identified as lead formate.<sup>38</sup> The formic acid probably came from oil-based paints or wood products used in the construction of the display case.<sup>33</sup>

### Specific Uses of Lead-based Materials

#### Architecture

Metallic lead is used in buildings for roofing and related purposes (in such features as flashing, gutters, and downspouts).<sup>39</sup> The lead is used either as sheet lead or else as a coating of lead or terne (lead-tin alloys with a dull gray



**Figure 3.** Lead formate crystals growing on a wheel of a toy chicken (Glenbow Museum T.63.46.18). The object had been exhibited for 9 years in a large sealed case. (Collection of Glenbow Museum, Calgary, Canada).

appearance) on copper, iron, or stainless steel.<sup>40</sup> Terne-coated copper was recently identified on the historic roof of the Library of Parliament in Ottawa.<sup>41</sup> Lead is sometimes used as a spacer or to anchor different material into masonry or metal, serving to accommodate thermal expansion/contraction and provide waterproofing.<sup>42</sup>

### *Sculptures*

Lead statues, garden urns, borders, planters, and basins are used outdoors, often associated with fountains or formal gardens.<sup>43,44</sup> The lead is sometimes painted or even gilded.<sup>45,46</sup> Lead is sometimes a component of copper alloys used for casting bronze statues and other sculptures. Furthermore, lead-based paint may be part of polychrome sculptures. This often occurs when they have been overpainted white, especially if they have been part of a 19<sup>th</sup> - or early 20<sup>th</sup> - century restoration.

### *Decorative and Utilitarian Objects*

Lead has been employed to make decorative and utilitarian objects from antiquity to the present.<sup>3,47</sup> It was used to make such items as ornately decorated water cisterns, caskets, urns, mortuary vases, coins, weight standards, weapons, ship anchors, seals, tokens, medals, and vases. Metallic lead was also inserted into objects to provide a stabilizing core, or to improve weight or balance. Sheets of lead were once used to line the areas of hulls of wooden ships that lay below the waterline. Lead was also mixed with tin to make pewter utensils (including plates, bowls, cups, jugs and spoons). Use of leaded pewter resulted in lead poisoning until the early 19<sup>th</sup> century when rigid specifications were established.<sup>48</sup>

Today, lead-antimony alloys (containing 11 wt% or less antimony) are the most widely used lead alloys and are found in a variety of products, including electrodes, connectors, lead shot, cable sheathing, and radiation shields.<sup>1</sup> Lead-antimony-tin alloys are used for casting objects such as belt buckles, trophies, casket trim, miniature figures, and hollow-ware. Lead can also be found in vintage cars (leaded seams) and in varying quantities in inexpensive children's jewellery. (As of June, 2005, it became illegal to market children's lead-containing jewellery in Canada. Under the *Children's Jewellery Regulations* in the HPA, these items must contain no more than 600 mg/kg total lead and 90 mg/kg migratable lead.<sup>49</sup>) Low melting (10-183°C) lead alloys contain large amounts of bismuth, tin, cadmium and/or indium and are used in items such as fuses, sprinkler system alloys, and foundry pattern molds. Modern pewter, an alloy of mainly tin with some antimony and copper, should be essentially lead free.

### *Solder*

Lead is mixed with tin to make soft solders (alloys that melt below about 450°C) for sealing and joining metals. The lead-tin mixture with the lowest melting point (183°C) contains 37 wt% lead and 63 wt% tin. Lead-tin solder can be used to seal copper pipes used in plumbing, but because lead can be leached from this solder into drinking water, lead-free solders (e.g., tin-silver solders) are now recommended.<sup>50</sup> (In Canada, the use of lead

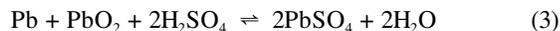
solder has been restricted under the National Plumbing Code, but compliance falls under the various provincial and territorial plumbing codes; some provinces have banned lead solder.) In the past, lead-tin solders were used to seal tin cans. Up until the early 1940s, the solder contained 63 wt% lead and 37 wt% tin, although solder with 98 wt% lead and 2 wt% tin was used for a time due to a tin shortage during the Second World War.<sup>51</sup> Inside tin cans for food which are lead-tin soldered, lead can be leached from the solder into the contents, especially when the foodstuffs are acidic, such as fruits and tomato products. In fact, lead poisoning may have been a factor in the failure of the 1845 Franklin expedition's search for the Northwest Passage, possibly from the food in lead-tin soldered tin cans or from other sources.<sup>52,53</sup> Today, cans are soldered with 100% tin. There are now lead-free solders on the market for essentially every purpose, so traditional lead-tin solders can be avoided.

### *Stained Glass and Windows*

In traditional stained glass windows, the coloured glass is supported by lead came (grooved strips of lead with an H-shaped cross-section) and these are joined using lead-based solder, typically with a 50:50 or 40:60 lead:tin ratio.<sup>54-56</sup> Modern stained glass is now often created using other metals such as zinc for the channels and lead-free solders.<sup>14</sup> The more recent copper foil method of joining the glass produces more fumes than assembly using came, because far more solder is required; the metal patinas used to finish the metal surfaces can also produce lead compounds (such as lead sulphide) which could be released during cleaning. Lead can also be a component of the body of the glass itself, as well as in some colourants, which can become airborne dust during grinding, bevelling, sandblasting or polishing. Traditional glass putties also contain high amounts of lead, which can cause significant exposure during repair of old windows; in addition, the window frames themselves were often painted with lead-containing paints.

### *Batteries*

The largest industrial users of lead are manufacturers of lead batteries.<sup>10</sup> Rechargeable lead-acid batteries are the most common and these have been in commercial use for over 100 years. These are the standard type of automobile battery, and can be charged and discharged many times. Lead-acid batteries are based on the following reaction:



During discharge, sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) reacts with lead and lead dioxide to form a layer of insoluble lead sulphate. Nickel-cadmium batteries contain lead hydroxide, and seawater batteries contain lead chloride. Lead-acid batteries can be found associated with historic vehicles and other equipment in industrial collections. The batteries are usually removed, drained of sulphuric acid, and stored dry.

### *Paint Used in Historic Buildings and Industrial Sites*

Lead was widely used as a major ingredient in most oil-based

paints prior to 1960, especially white and pastel shades. Some paints contained as much as 50% lead by weight. These paints were widely used on exterior wooden surfaces (including house and window trim, doors, and shutters), interior wooden surfaces (trim, mantels, staircases, and panelling), and metal surfaces (industrial, household and farm equipment). Red lead was popular as a metal primer because of its ability to act as a corrosion inhibitor.<sup>57,58</sup> Until the early 1950s, the lead paint industry even promoted its products as safe and marketed them to children, as did the National Lead Company, for example, through their iconic Dutch Boy.<sup>59,60</sup>

By the late 1970s, the use of lead in paints decreased significantly in North America, although lead compounds were still being used as corrosion inhibitors, pigments and driers. In 1976, Health Canada passed the *Liquid Coating Materials Regulations* under the HPA, which limited the amount of lead in interior consumer paint to no more than 0.5 w/w %. Under the HPA, the importation, advertisement, or sale of pencils, artists' brushes, children's toys, equipment and furniture which had more than 0.5 w/w% lead in an applied coating such as paint or varnish was prohibited. Since 1991, Canadian paint manufacturers have voluntarily refrained from using lead in interior or exterior paint for consumer use. Under the new 2005 *Surface Coating Materials Regulations* in the HPA, the legal lead content of consumer paints and other surface coating materials (some special use surface coatings are exempt) has been reduced to 600 mg/kg (0.06 w/w%) total lead. Concurrent legislation reduced the maximum legal lead limit of surface coatings on children's products and artists' brushes and pencils to the same level.<sup>61</sup>

Lead-based paint is a particular hazard when it becomes loose and flaky as older painted surfaces deteriorate (by peeling, chipping, chalking or cracking) and wear (through such activities as opening and closing windows) to form lead-laden dust particles.<sup>57</sup> Settled lead dust can then reenter the air when people vacuum, sweep or walk through it. Moreover, lead poisoning can result when lead paint is being removed. Workers have developed lead poisoning by sanding or using a propane torch to strip lead-based paint, by using a heat gun to soften thick lead-based paint prior to scraping, and by using a motorized wire brush on exterior lead-based paint.<sup>8,9,62</sup>

### Modern Pigments

Although lead-containing pigments are now severely restricted in consumer paints, the *Surface Coatings Materials Regulations* in the HPA permit the use of lead pigments in artistic paints, defined as "material for the purposes of arts, crafts, or hobbies, other than material for use by children." This definition includes pigments used in printmaking, silk screening and the colouring of soft vinyl and leather items. Any artistic paints and pigments with more than 600 mg/kg total lead must carry precautionary labelling. Primers and paints for signs, road vehicles and boats are exempt from the *Surface Coating Materials Regulations*.

Many paint manufacturers identify their colourants using information based on the internationally accepted Colour Index

(C.I.) system, specifying the C.I. name (which identifies the colourant as a pigment or dye) and C.I. constitution number (which identifies the chemical composition).<sup>63</sup> Summarized in **Table III** are inorganic lead-containing compounds listed by their C.I. constitution number, which were used in C.I. pigments commercially available in 1982.<sup>63</sup> Also listed in **Table III** are the C.I. pigments in which a lead compound is a component, and the chemical name and formula. There are also a few lead-containing organic pigments (e.g., C.I. Pigment Red 90, C.I. 45380:1, a lead salt of an organic acid dye); these are not included in **Table III**. A smaller number of lead-containing compounds are listed in the more recent publications of the Colour Index as fewer lead-containing pigments are still commercially available. Details about specific coloured lead pigments are provided in the following sections.

It is possible for inorganic mineral pigments to be contaminated with lead. Titanium oxide, zinc oxide and many others may contain lead if they are obtained from a natural source, such as a mine. Mixtures of pigments may also be inaccurately labelled. One artist, for example, was accidentally poisoned by lead when she mixed up a paste from a white powder labelled "titanium white" (which actually contained 47 wt% lead, probably white lead) and then applied the paste to a canvas with her hands.<sup>5</sup> When in doubt about a pigment, test it for lead.

**White:** The C.I. Pigment White 1 contains lead carbonate hydroxide (C.I. 77597) and lead carbonate (C.I. 77596). This pigment is also known as white lead and it has been used from late classical times until fairly recently.<sup>64</sup> It was one of the first synthetic pigments made by Pliny (by the reaction from vinegar on lead sheets) and, over the years, many different processes have been developed to mass produce this pigment.<sup>11,65,66</sup> White lead, although now difficult to obtain, was one of the main white pigments used in easel painting.<sup>67</sup> It was also used as a major component in the ground layer, and in patches and adhesives for canvases. Its good physical properties, when mixed with linseed oil and dried, have been attributed to the formation of a lead soap, lead linoleate;<sup>67</sup> however, some paint films have been noted to darken through formation of lead sulphide.<sup>64</sup> Lead carbonate hydroxide (also called basic lead carbonate) occurs in nature as the mineral hydrocerussite.<sup>68</sup> Lead carbonate exists in nature as the mineral cerussite.

The C.I. Pigment White 2 (basic lead sulphates) contains lead oxide sulphates (C.I. 77633). The C.I. Pigment White 3 contains lead sulphate (C.I. 77630), which occurs in nature as the mineral anglesite. C.I. Pigment White 16 consists of lead silicate (C.I. 77625) and C.I. Pigment White 30 contains lead phosphate (C.I. 77622). Lead chloride hydroxide (C.I. 77593) occurs in nature as the mineral laurionite and is known as the artists' pigment Pattinson's white.<sup>10,66</sup> Finally, lead phosphite (C.I. 77620) has been used as a white anticorrosive pigment.<sup>66</sup>

**Red and Orange:** The C.I. Pigment Red 105 contains lead tetroxide (C.I. 77578) which has a brilliant scarlet-orange colour, occurs in nature as the mineral minium, and is also known as the pigment red lead.<sup>69</sup> In ancient times and throughout the Middle

Table III: Lead-containing Compounds Listed as Pigments in the 1982 Colour Index (C.I.).<sup>63</sup>

C.I. Constitution Number	C.I. Pigment in which the C.I. Number is a component	Chemical Name and Formula as listed in C.I.
77575	Metal 4	metallic lead
77577	Yellow 46	litharge PbO
77578	Red 105	lead orthoplumbate $Pb_3O_4$
77579		lead sesquioxide $Pb_2O_3$
77580		lead peroxide $PbO_2$
77585		lead aluminate $PbO \cdot Al_2O_3$
77588	Yellow 41	lead antimonate or lead metantimonate $Pb_3(SbO_4)_2$ or $Pb(SbO_3)_2$
77589	Yellow 41	lead antimonate + zinc and bismuth oxides $Pb_3(SbO_4)_2 + ZnO + BiO$
77592	Yellow 30	lead oxychloride $PbCl_2 \cdot 5-7PbO$
77593		$Pb(OH)_2 \cdot PbCl_2$
77596	White 1	lead carbonate $PbCO_3$
77597	White 1	basic lead carbonate $3.6PbCO_3 \cdot Pb(OH)_2$ to $1.8PbCO_3 \cdot Pb(OH)_2$
77600	Yellow 34, Green 15 (component)	lead chromate $PbCrO_4$
77601	Orange 21, Orange 45, Red 103, Green 15 (component)	basic lead chromate $xPbCrO_4 \cdot yPbO$ or $xPbCrO_4 \cdot yPb(OH)_2$
77603	Yellow 34, Green 13 (component), Green 15 (component)	lead sulphochromates $PbCrO_4 \cdot xPbSO_4$
77605	Red 104	lead chromate-lead molybdate mixed crystals
77607		lead dichromate
77610	Yellow 48	lead cyanamide $Pb(CN)_2$
77613		lead di-iodide $PbI_2$
77620		dibasic lead phosphite $2PbO \cdot PbHPO_3 \cdot \frac{1}{2}H_2O$
77622	White 30	lead phosphate $Pb_3(PO_4)_2$
77625	White 16	lead silicate
77629		lead stannate
77630	White 3	lead sulphate $PbSO_4$
77633	White 2	basic lead sulphates varying from $5PbSO_4 \cdot PbO$ to $2PbSO_4 \cdot PbO$
77640		lead sulphide $PbS$
77645	Yellow 47	lead titanate $PbTiO_3$
77650		lead tungstate $PbWO_4$

Ages, red lead was used as a pigment in paintings because it was cheap and easy to make.<sup>3,11</sup> It is used in anti-corrosion paints and in primers for bare metal surfaces,<sup>42,65</sup> but is now being phased out because of environmental restrictions.<sup>11</sup> The C.I. Pigments Red 103, Orange 21, and Orange 45 contain lead chromium oxide (C.I. 77601), the colour of which depends on the composition and particle size.<sup>66</sup> Lead chromium oxide exists in nature as the mineral phoenicochroite, and is also known as chrome orange, chrome red, or basic lead chromate.<sup>66</sup> Another red pigment is C.I. Pigment Red 104. It contains lead chromate-lead molybdate mixed crystals (C.I. 77605).

**Yellow and Green:** The C.I. Pigment Yellow 46 contains lead monoxide (C.I. 77577) which exists in nature as the mineral massicot, and has been used as a pigment called yellow lead.<sup>67</sup> In the past, this material was known to painters as litharge, but it is different from the mineral litharge which has a red colour.<sup>69</sup> The C.I. Pigments Yellow 34, Green 13, and Green 15 contain lead chromate (C.I. 77600) and/or lead sulphochromates (C.I. 77603). Lead chromate exists in nature as the mineral crocoite, and is sometimes called chrome yellow or lead chrome yellow.<sup>67</sup> (Chrome yellow was once used as a food dye for cakes and buns which, in 1887, resulted in an outbreak of mass lead poisoning in Philadelphia.<sup>51</sup>) The C.I. Pigment Yellow 41 contains lead antimony oxides (C.I. 77588) or lead antimony oxides mixed with zinc and bismuth oxides (C.I. 77589). Lead antimony oxide exists in nature as the mineral bindheimite and the orange-yellow colour of the powdered mineral was used as a colourant for ancient glasses and glazes,<sup>3,10</sup> as well as for the yellow pigment called Naples yellow.<sup>70</sup> Three other C.I. yellow lead-containing pigments are Yellow 30 (C.I. 77592, lead oxychloride), Yellow 48 (C.I. 77610, lead cyanamide), and Yellow 47 (C.I. 77645, lead titanate). Lead stannate (C.I. 77629) is listed as a yellow lead-containing component in C.I. Pigments. This compound is also known as lead tin yellow (lead tin oxide) and it was used in European paintings between approximately 1300 and 1750.<sup>71</sup> Lead sesquioxide (C.I. 77579) is also listed as a yellow component in C.I. Pigments.

**Blue, Brown, Black:** Lead sulphide (C.I. 77640) is listed as a component in C.I. Pigments (in 1982) for use as a brown to black hair dye. Lead sulphide exists in nature as the mineral galena and it is listed as a component in pigments called "sublimed blue lead," "blue lead," or "blue basic lead sulphate."<sup>65,66,72</sup> At one time, a thin coating of lead sulphide was applied to glass surfaces in car rear-view mirrors to limit the reflectivity.<sup>66</sup>

#### *Driers*

Lead compounds (referred to as driers) are added to drying oils in paint (such as linseed oil) because they dissolve and generate lead ions which catalyze the drying process.<sup>66,73</sup> Lead compounds used as driers include lead oxide and lead soaps (such as lead stearate or lead oleate).<sup>67,74</sup>

#### *Glazes and Enamels*

Lead poisoning has been associated with pottery making for hundreds of years and can still happen. (In 1969, a family of five

in California developed lead poisoning after storing orange juice in an earthenware jug from Mexico.<sup>51</sup>) Ceramic glazes are a thin coating of glass applied over a body of clay (such as pottery) during the manufacturing process, to make the surface smooth and waterproof. Enamels generally are a thin layer of glass bonded to a metal surface (as in bowls, sinks, and bathtubs) and serve the same purpose as glazes. Both are made using complex mixtures of silicon dioxide (glass), pigments, and fluxes to promote melting. Lead is present in glazes and enamels because lead compounds (including lead monoxide, lead tetroxide, lead carbonate hydroxide, and lead sulphide) are used as fluxes or as pigments.<sup>75</sup> The main reason for the popularity of lead-containing fluxes is the resulting low firing temperature, important for earthenware and craft pottery. Their presence also helps to improve the adhesion of the glaze and to add brilliance to the finished product. Lead fumes, given off during firing of lead glazes, can contaminate non-lead pottery that is being fired in the same kiln and can escape from the kiln and settle as fine dust in the room if the kiln is not properly vented.

Glazes made from frits can also contain lead. Frits are amorphous glass powders made by melting ingredients together (including fluxes), cooling, and then grinding the resulting glass into a powder for use as a starting material for making glazes and enamels.<sup>14</sup> Frits were originally developed for the British pottery industry to reduce workers' deaths from lead poisoning by binding free lead into lead silicates, but their solubility in the final state is variable, even being similar to that of toxic lead oxides, and both the frits and the finished glazes remain a hazard.<sup>76</sup>

Finished lead glazes (i.e. fired glazes made from lead frit glazes or raw lead glazes) may release significant amounts of lead. In Canada, under the *Glazed Ceramics and Glassware Regulations* in the *HPA*, finished glazes must not release more than 3.0 mg/L of lead (after soaking for 24 hours in 4 v/v % acetic acid), or less, depending on the type and size of the ceramic ware or glassware. In the case of mugs and glasses with a decorative glaze within 20 mm of the rim, the product cannot release more than 25 mg/L of lead. This limit will be reduced to 4 mg/L in 2005 under a pending amendment to the *Regulations*.

#### *Leaded Crystal*

Leaded crystal is produced by adding lead compounds, such as lead oxide, to molten quartz; the resulting glass has a high density and brilliance. Today, leaded crystal typically contains 24 to 32 wt% lead oxide. Liquids, especially alcohol-based or acidic ones (wine or orange juice, for example) stored for long periods in leaded crystal containers such as decanters are known to become contaminated with lead.<sup>77,78</sup>

#### *Polymers, Plastics, and Rubber*

Lead compounds are added to certain plastics and rubbers to act as heat and light stabilizers, to improve their properties, or as plasticizers.<sup>10</sup> Lead stearate and dibasic lead stearate, for example, are among the leading general-purpose stabilizers for poly(vinyl chloride) and its copolymers.<sup>66</sup> Many of these

materials find their way into collections containing modern artifacts. The lead compounds can migrate to the surface of the plastics, where they then become available to be absorbed through skin contact. A simple spot test has been developed for detecting lead in vinyl window blinds,<sup>79</sup> which can be adapted for use on museum objects containing similar plastics. These comprise a wide range of artifacts, including such diverse items as toys, vinyl purses, decals, and electrical or telephone wire with coloured insulation.

#### *Textiles*

Thin strips of lead metal are used as weights at the base of curtains, and lead compounds can be present in pigments (as impurities) used to colour fabric. The danger of such impurities was demonstrated when a textile conservator developed lead poisoning after working on a Peruvian tapestry using antique powdered pigment.<sup>6,7</sup> The antique pigment contained about 1% lead and she inhaled the dust and possibly ingested some of the pigment by wetting the thread with her mouth. Lead compounds, such as lead acetate, are sometimes used in a process to add overall weight to silk.<sup>80</sup> Furthermore, lead soaps (for instance, lead oleate) are used to produce water-repellent cloth because of their insolubility in water and hydrophobic properties; they also help to protect against mildew.<sup>66</sup>

#### *Medicine*

Lead compounds were among the first drugs of mineral origin (because they are toxic and so have antiseptic properties) and they are still widely employed in herbal or traditional medicines of Asia, Africa, and South America.<sup>3,81</sup> Lead sulphide, for example, was used as an eye salve in ancient Egypt, and white lead compounds were used in preparing other salves. Saturnine (lead-containing) drugs were gradually accepted for the treatment of a number of diseases. Lead acetate (one of the few lead compounds readily soluble in water) was the compound of choice for the majority of lead-based medications for internal use. As recently as the 1940s, lead-containing remedies were still in use (such as lead acetate hydroxide in a poison ivy lotion).<sup>81</sup> Museum collections comprising medicine kits or bottles may contain such materials.

#### *Cosmetics*

Lead compounds, such as white lead, are used in certain cosmetic products. In Canada, they are now prohibited from use.<sup>82</sup> Lead monoxides were used in ancient China as a fashionable colour for the adornment of faces.<sup>3</sup> During the reign of Elizabeth I of England, white lead was popular for use as a face cosmetic.<sup>83</sup> More recently, lead carbonate was discovered in theatrical makeup (and its presence caused lead poisoning of at least one actor who used a lead-based powder).<sup>84</sup> Lead sulphide is used in certain dark-coloured eye cosmetics to make the eyes appear larger and brighter.<sup>81</sup> Surma and kohl are examples of eye makeup still commonly used in the Indian subcontinent and in many Arab nations and Muslim communities; some contain up to 80% lead sulphide.<sup>51,85</sup> Lead compounds such as lead acetate are also used to progressively darken the colour of hair because

the lead ions react with the sulphur in hair to form dark-coloured lead sulphide; these products were prohibited in Canada in May, 2005. Lead-containing cosmetics may still be encountered in collections of household materials.

#### *Organic Lead Compounds*

The organic lead compounds tetraethyl lead and tetramethyl lead were added to gasoline as anti-knock agents, starting around 1923 in the United States.<sup>22,51</sup> The use of leaded gasoline then spread around the world. Because of environmental concerns, leaded gasoline was being phased out by the 1980s, at least in Canada and the United States, and it was banned from use in Canada in December, 1990. Although many countries around the world have phased out the use of leaded gasoline, others have not and it is still being used today in some parts of the world.<sup>22</sup> For information on the phase-out program, refer to the website of the International Lead Management Center (see **Table I**). Engines in historic vehicles that were designed to run on leaded gasoline can be damaged when unleaded gasoline is used. A limited amount of leaded gasoline is still available for operating historic vehicles (as well as being used in racing cars world-wide), but there are also lead-free replacement fuels available with alternative anti-knock agents.

#### **Occupational Health and Safety Legislation**

In Canada, applicable legislation for occupational health and safety varies between location and employer. Each of the ten provinces, three territories, and the federal government has its own occupational health and safety legislation. The federal government has responsibility for the health and safety of its own employees, federal corporations, and workers in certain industries (about 10% of the Canadian workforce). The remaining 90% of Canadian workers are covered by legislation of the province or territory where they work. A key website that lists the current agencies (federal, provincial, territorial) responsible for occupational safety and health legislation can be found at Canada's National Occupational Health and Safety Website (see **Table I**). Information about occupational health and safety can also be obtained from the Canadian Centre for Occupational Health and Safety (CCOHS).<sup>86</sup>

#### *Workplace Hazardous Materials Information System (WHMIS)*

WHMIS is a Canada-wide system designed to give employers and workers information about hazardous materials in the workplace. The key elements are worker education programs, and mandatory provision (under the requirements of the HPA) of Material Safety Data Sheets (MSDSs) and safety labelling on the containers of controlled products, materials and substances. MSDS requirements and supplier labelling are governed by the HPA and the *Controlled Products Regulations*, both of which are administered by Health Canada.<sup>87</sup> An MSDS is a form which provides information on the hazards of a product along with the precautions required for its safe use. These forms are filled out and provided by the manufacturer of the product. WHMIS does not place limits on the use of any hazardous products or materials in the workplace. The minimum concentration of lead

for disclosure on an MSDS varies from 0.1% to 1.0% by weight, depending on the form of the lead. Minimum disclosure concentrations for lead compounds are listed in the Ingredient Disclosure List (items 929-945) under the HPA.<sup>88</sup> Each of the federal, provincial, and territorial agencies responsible for occupational health and safety have established employer WHMIS requirements within their respective jurisdiction. All employers in workplaces where hazardous materials are present are required to develop programs and train their employees. WHMIS legislation requires that product MSDSs be made available to those who use or could be exposed to potentially hazardous products. They are also posted on numerous websites.<sup>89</sup>

#### *Lead-specific Regulations*

Anyone working with lead-containing materials, where they are likely to inhale, ingest or absorb lead, should obtain a copy of the current occupational health and safety regulation which is pertinent to lead from the agency responsible for their jurisdiction. The information can be found either in the Occupational Health and Safety Regulation (under the section dealing with hazardous materials), or in a stand-alone regulation (dealing specifically with lead). They should also revisit this information periodically, as legislation is amended from time to time. In addition to the legislation, there are also guidelines specific to lead available on line from the provincial government websites for Alberta,<sup>90</sup> British Columbia,<sup>91</sup> Manitoba,<sup>92</sup> Ontario<sup>93</sup> and Québec.<sup>94</sup>

#### *Occupational Exposure Limit (OEL)*

Occupational health standards for lead specify an Occupational Exposure Limit (OEL) for the amount of lead allowed in the air to ensure that individuals are not exposed to unsafe levels of lead *via* inhalation. Some agencies set their own OELs in their occupational health standards, but most base their OELs on the most current Threshold Limit Value (TLV) set by the ACGIH.<sup>12</sup> For elemental lead and most inorganic lead compounds, the ACGIH has set the TLV/TWA (time-weighted average) for an 8-hour work day and a 40-hour work week at 0.05 milligrams of lead per cubic metre of air (0.05 mg m<sup>-3</sup>). [This is equivalent to 50 micrograms of lead per cubic metre of air (50 µg m<sup>-3</sup>).] Workers exposed to airborne lead up to this TLV/TWA limit during a conventional 8-hour workday and 40-hour work week should not be adversely affected.<sup>12</sup>

Air sampling and analysis are usually required to monitor the amount of airborne lead to assess worker exposure and to determine if the TLV limit has been exceeded.<sup>14</sup> Air sampling involves the collection of an air sample by a qualified person using a small filter and pump, followed by delivery of the samples to a laboratory for analysis by an appropriate standard method. Occupational health and safety regulations may specify the exact method to be used for determining airborne lead or they may simply require that it be done in accordance with standard methods for workplace air sampling and analysis. The National Institute for Occupational Safety and Health (NIOSH), for example, has developed several analytical methods (e.g.,

Methods 7082, 7105, 7300, 7701) that can be used for determining airborne lead.<sup>95</sup> A list of laboratories accredited for industrial hygiene monitoring in Canada is included on the website for the American Industrial Hygiene Association (see **Table I**).

#### *Medical Surveillance*

Testing blood for its lead level is a useful method for detecting recent lead exposure and in monitoring whether the protection against lead exposure used by a worker has been adequate. Lead regulations usually require regular testing of blood-lead levels and often specify the level above which the worker must be removed from further exposure. In Ontario, for example, the lead regulation states that when the blood-lead level exceeds 3.4 µmol/L, a second test must be taken, and, if this test also shows levels above 3.4 µmol/L, the worker must be removed from lead exposure (with the exception being women capable of bearing children – they must be removed from lead exposure when their blood-lead level exceeds 1.95 µmol/L).<sup>96</sup> However, the current workplace TLVs are not considered sufficient to protect the fetus, as recent studies have shown that there is no known level of lead in the blood that does not have some degree of adverse effect on the mental acuity of children.<sup>97</sup>

#### **Controlling Occupational Exposure to Lead**

This section provides information on controlling and minimizing exposure to lead, adapted from the systematic approach used by industrial hygienists.<sup>98</sup> They consider engineering controls (isolation or ventilation) as the first lines of defense, followed by administrative controls (housekeeping, personal hygiene, storage and disposal programs). The last line of defense is personal protective equipment (respirators and protective clothing).

#### *Engineering Controls*

##### Isolation

Ideally, work involving lead-based materials should be contained and isolated from any surrounding workspace using enclosures under negative pressure. The enclosure should not vent outside, to prevent contamination of the environment. Such isolation approaches are taken in conservation when dealing with the removal of lead-based paint from historic houses (lead remediation projects). Additional information can be found in references cited in a later section called *Lead-based Paint Removal*.

##### Ventilation

Local exhaust ventilation, fume hoods, and down-draft benches draw lead fumes or dust away from the work area. They should be used at the point of generation of the lead-based material, and in a way that air is not being drawn past a worker's breathing area. These systems need to be maintained regularly and filters changed. Down-draft benches with slot vents are particularly useful when soldering, to minimize exposure to decomposition products from the soldering process. Also available for the desk

top are small portable local exhaust systems with flexible ducts and a High Efficiency Particulate Air (HEPA) filter. HEPA filters are rated to trap 99.97% of particles 0.3 microns (0.3  $\mu\text{m}$ ) and larger. These portable units are useful for removing dust and larger fume particles, but do not remove gases, such as decomposition products generated when soldering with fluxes and rosins. An industrial hygienist should be consulted about appropriate ventilation techniques for dealing with lead fumes or lead dust.

### *Administrative Controls*

#### Personal Hygiene

Good personal hygiene is an important control measure and can minimize exposure to lead. Eating, drinking, and smoking should not be allowed in the workspace because these activities easily transfer lead contamination from the hands into the mouth. Washing hands, face, neck and arms before eating and drinking or smoking will reduce the ingestion hazard.<sup>16</sup> After working with a lead-based material, work clothes should be changed and a shower taken (if possible) before going home, to prevent lead dust from being taken home and spread to others, especially to children. If the studio is located in or near the home, children should never be allowed into areas where lead is being worked on or used.<sup>14</sup>

#### Housekeeping

Good housekeeping plays a key role in the control of occupational health hazards. One of the best ways to minimize exposure to lead dust contamination in the workplace is to keep the work area clean, especially after working on anything containing lead or lead compounds. Regular vacuuming with a vacuum cleaner equipped with a HEPA filter is highly recommended. Cleaning up contaminated dust should not be done with a broom, a conventional vacuum cleaner (one that does not have a HEPA filter), a dry mop, or compressed air, because any lead contamination is blown around the workplace, with the finest dust (the most dangerous) scattered into the air. HEPA filters are expensive to replace, so the more cost-effective vacuums are ones with a greater number of filter stages which restrict the particles reaching the HEPA filter, therefore maximizing its lifetime. For more information on commercially-available HEPA vacuum cleaners, the reader is referred to publications by Stavroudis and Shtum,<sup>99</sup> and Guild and MacDonald.<sup>100</sup>

After vacuuming to remove lead dust and other debris, all surfaces in the workspace (the area covered by the plastic specified in the section below on general guidelines for working with lead-containing materials) and nearby (to about 0.6 m (2 ft) outside the plastic) should be cleaned using wet cleaning or damp mopping methods. Phosphate-rich detergents, such as trisodium phosphate (TSP), have been recommended by Stavroudis, who suggests that they make the lead less bioavailable.<sup>101</sup> A mild detergent can be used on those surfaces where the finish is likely to be marred by the use of trisodium phosphate.

There are also commercially-available phosphate-free anionic detergents sold for cleaning lead-contaminated surfaces. Ledizolv, for example, is a lead-specific detergent sold by LSZ Inc. There are also products designed for removing heavy metal contamination (including lead) from skin, equipment and laundry, such as D-Lead cleaning products made by Esca Tech.<sup>102</sup>

#### Storage and Disposal of Hazardous Waste

After working on lead-based objects, the lead-based debris and other lead-contaminated material should be collected, contained, labelled, and in most cases, disposed of as hazardous waste. Lead dust must not be allowed to become airborne during the collection and removal process. Instructions for disposal can be obtained from the local municipal government, the waste management agency in the area, or the provincial/territorial Department or Ministry of Environment. In Ontario, waste is considered hazardous if the leachate (generated by a Toxicity Characteristic Leaching Procedure) contains more than 5 mg/L (5 ppm) of lead.<sup>103</sup>

#### *Personal Protective Equipment*

#### Respirators

Respiratory protection is used to prevent a user from inhaling airborne lead dust, fumes or mist when engineering and administrative control measures are not sufficient to achieve acceptable limits of exposure. Respirators are either an air-purifying or supplied-air type. In North America, NIOSH is the only organization to test and certify respirators, and its standards are used by Canadian occupational health and safety agencies. Each type of respirator has an Assigned Protection Factor (APF). A respirator with an APF of 10 means that a user (when properly fitted and trained) can safely work in an environment that contains 10 times the TLV.<sup>92</sup>

In June, 1995, NIOSH updated and modernized the regulation for certifying air-purifying particulate respirators. The revisions define nine classes of air-purifying respirators based on filter efficiency and use limitations. The three levels of filter efficiency are 95%, 99% and 99.97%; the last one is usually shortened to 100% and is also rated as a HEPA filter. The three categories of resistance to filter efficiency degradation are N (not resistant to oil), R (resistant to oil), and P (oil-proof). The P100 is the only filter assigned a distinctive magenta color.<sup>14</sup>

Air-purifying respirators (half facepiece) with an APF of 10 are used when lead is present in relatively low concentrations (i.e., in environments containing up to 10 times the TLV). Depending on the applicable regulation, a filter efficiency of 95, 99, or 100% may be acceptable. However, due to the high toxicity of lead, 100% is recommended.<sup>104</sup> For higher levels of airborne lead, a respirator with a higher protection factor should be used such as a supplied-air respirator.<sup>93</sup> High airborne lead levels can be generated by many activities, including: brazing; hand scraping or dry sanding lead-based paints; spray application of lead-containing coatings; and by using power tools (without

effective dust collection and HEPA filters) or air-abrasive techniques for removing lead-based paints.

Respirators should be fit-tested by a qualified individual to ensure a proper seal between the face and the face piece. More information on respirators can be found in publications by the Canadian Standards Association,<sup>105</sup> Colton,<sup>106</sup> Guild and MacDonald,<sup>100</sup> and Rossol.<sup>14,104</sup>

#### Protective Clothing

Either reusable or disposable protective clothing (items such as a lab coat, gloves, coveralls, and shoe coverings) should be worn to prevent contamination of personal clothing and the transfer of contamination from the work area to lunch and break areas, vehicles and homes. Features to look for in disposable coveralls include material designed to reduce dust retention, close-fitting neck and arm openings, and, in certain situations, the use of breathable material to reduce the potential for heat stress. Contaminated disposable clothing should be treated as hazardous waste. Depending on the nature of the work or the chemicals being used, other personal protective equipment, such as hard hats, goggles or safety boots, may need to be worn. When dealing with chemicals, consult the MSDS to determine the required protective equipment.

To minimize exposure to surface and airborne lead that has accumulated on clothing and to ensure the health and safety of their employees in the workplace, employers should be encouraged to implement procedures for cleaning, laundering and disposing of protective clothing and equipment. They should also ensure that protective clothing and equipment is repaired or replaced to maintain its effectiveness, that all protective clothing is removed at the end of a work day only in designated change areas, and that contaminated clothing is placed in a closed container in the change area to prevent the spread of lead contamination.

#### **General Guidelines for Working with Lead-containing Materials**

Provided in this section are some general guidelines for conservators working on a project involving lead-based materials. These guidelines have been adapted from information published by Stavroudis,<sup>107</sup> who summarizes techniques to contain lead contamination for low risk exposure to lead, such as is experienced by many conservators working on small objects in their studios. Stavroudis based his material on guidelines published by the U.S. Department of Housing and Urban Development (HUD).<sup>108</sup>

Before starting a project, test for the presence of lead on an artifact or in the workspace, using methods such as laboratory analysis or a simple spot test (this may involve checking paint samples, for example, or dust collected at the bottom frame of a painting; **Appendix 1** describes methods for paint testing), and do any relevant air sampling and analysis of the environment under working conditions, as specified by applicable legislation. Check the MSDS for each product used in a conservation studio

or laboratory for essential information on composition and toxicity. An MSDS for lead solders, for example, will reveal whether any highly toxic metals (such as arsenic, cadmium, or beryllium) are present in the alloy. The seller of any hazardous product is obliged to provide an MSDS, or one can be obtained from the many websites that post them.<sup>89</sup> It is essential to research the relevant federal, provincial, or territorial occupational laws for working with lead-based materials and environmental laws for disposal of lead-contaminated materials. Establish any necessary monitoring programs, such as monitoring airborne lead or medical surveillance. Rossol, an industrial hygienist, recommends that anyone occupationally exposed to lead in any form have their blood-lead levels tested at least once a year.<sup>14</sup> Everyone involved in the project should be trained and prepared to comply with the regulations.

For a workspace for relatively small objects, clear the surrounding area to minimize contamination of other surfaces with lead dust, or wrap items with polyethylene to keep lead dust from settling on them. Place two layers of polyethylene, preferably 0.15 mm (6 mil), on the workspace, extending about 1.5 m (5 feet) beyond the work area needed for the lead-containing object. During the conservation project, clean up the work area daily. Use the top layer of polyethylene to contain all hazardous debris (including paint chips, cleaning media, used vacuum filters, used respirator filters, and other lead-contaminated items), and seal it with duct tape. Wrap the second layer of polyethylene around the first bundle, seal it, and label as hazardous waste. Store all lead-contaminated materials according to appropriate government regulations for hazardous waste. Vacuum the work space with a HEPA vacuum cleaner. Wet mop or wet wash the work space with an appropriate detergent, and to be safe, HEPA vacuum again. Replace the two layers of polyethylene.

During the entire conservation project, use appropriate ventilation or wear suitable respiratory protection where respirable lead dust is being produced above the regulated exposure limit (e.g., TLV) and until the lead dust has been removed from the work space. Wear appropriate protective clothing. Practice good personal hygiene. Change from work clothes before eating or leaving the site. Wash meticulously (face and hands) before eating. Shower at the end of each work day. Finally, monitor according to the established program.

After completion of the project, give the workspace one final thorough cleaning. Launder reusable clothing such as lab coats and dispose of all lead-contaminated materials, including disposable clothing, according to appropriate government regulations for hazardous waste. Liquid waste (for example, chemical paint strippers) also needs to be disposed of properly.

#### **Conservation-specific Concerns**

##### *Lead-based Paint Removal*

Special care must be taken by anyone involved with the removal of lead-based paints from historic buildings or historic industrial sites prior to repainting. Such work can generate large quantities

of airborne dust, especially if carried out using uncontained abrasive blasting techniques. (Similarly, conservators working on stained glass windows need to take special care because such work also has the potential to generate large amounts of lead dust.) Paints need to be analysed to determine if lead is present at a level above which it is considered hazardous (recently lowered to 0.06 w/w % lead under the *HPA*). **Appendix 1** contains more information about determining lead levels in paint.

Studies have shown that methods for the removal of lead-based paint, such as uncontained abrasive methods (including dry sanding, power sanding, grinding, and abrasive blasting) or heating methods (particularly open flame burning and hot-air guns), can generate large quantities of lead dust and fumes, and cause high occupational exposures to lead.<sup>109</sup> Such methods should be avoided, especially the dangerous practice of using open flame gas or propane torches to remove paint.

Safer methods for removing lead-based paint are based on using HEPA-vacuum-contained abrasive methods, hand scraping (usually wet), chemical strippers, or a heat gun operated at temperatures under 500°C.<sup>109</sup> When scraping by hand, local containment can be achieved by aiming the nozzle of a HEPA vacuum cleaner directly at the area where the work is being done.<sup>58</sup> New forms of sanders are available with attached HEPA vacuum hoses to control dust.<sup>57</sup> Wet methods (such as wet sanding, wet scraping, or chemical stripping) for removal of lead-based paint have the advantage of keeping lead-contaminated dust from becoming airborne.<sup>57</sup> When using chemical strippers, suitable precautions as listed in the product MSDS must be taken, especially if methylene chloride (dichloromethane) is present, as it is listed as A3 (confirmed animal carcinogen) by ACGIH.<sup>12</sup>

More information for reducing hazards when dealing with lead-based paints can be found in general guidelines published by Rosso<sup>14</sup> and by Matte et al.<sup>16</sup> In addition, guidelines have been published for dealing with leaded paint removal in historic buildings<sup>57,110</sup> and industrial sites.<sup>58</sup> There is also general information about lead-based paint removal from homes available from the Canadian Paint and Coatings Association,<sup>111</sup> Canada Mortgage and Housing Corporation,<sup>112</sup> Health Canada,<sup>113</sup> and the U.S. Department of Housing and Urban Development.<sup>114</sup>

#### *Lead Weights in Conservation*

Lead, either as solid ingots or lead shot, is used in conservation as weights in treatments and as counterweights in display cases. Unfortunately, uncoated lead metal can generate lead dust which then contaminates the workspace if the lead has not been properly contained. Stavroudis suggests two approaches for encapsulating lead.<sup>101</sup> He recommends sealing lead shot inside two layers of 0.15 mm (6 mil) polyethylene, which can then be covered with cloth or leather. He also suggests painting lead ingots with a polyurethane coating followed by a layer of textured paint (to prevent the surface from being too slippery). A better approach may be to replace the lead with less toxic material such as flat polished stone slabs, bismuth shot, polypropylene pellets, or steel balls.<sup>115</sup>

#### *Cleaning Lead Coupons*

When lead coupons are prepared for use in accelerated corrosion tests (such as the Oddy test<sup>116</sup>), proper care should be taken to avoid generating lead dust and to contain the waste material. Stavroudis recommends wearing disposable gloves, working on two layers of 0.15 mm (6 mil) polyethylene, and using wet abrasive polishing rather than dry.<sup>117</sup> He suggests enclosing all waste material (gloves, paper towels contaminated with lead-containing water, abrasive paper, etc.) in the upper plastic (sealed with duct tape), and then wrapping the lower plastic sheet around the bundle and sealing it. This bundle should then be disposed of properly as hazardous waste.

#### **Conclusions**

The main purpose of this paper is to increase the awareness of the toxicity of lead and its compounds, particularly in a conservation context. Lead can be ingested, absorbed through the skin, or inhaled, especially if it is in the form of a fine lead dust, mist or fumes, which can result in lead poisoning. This paper covers many aspects of lead, including a description of the variety of situations in which lead is likely to be encountered in museums, cultural heritage sites, or other institutions.

Appropriate safety precautions need to be followed when dealing with lead-containing objects to minimize exposure to lead. In general, this is accomplished by using a combination of engineering and administrative controls and/or the use of personal protective equipment. Although general guidelines are summarized in this paper, the appropriate government agency dealing with occupational health and safety must be consulted for the current local regulations for working with lead and disposing of hazardous lead waste.

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#### **Appendix 1. Techniques for Identifying Lead in Paint**

##### *Laboratory Testing*

When there is a need for quantitative analysis for lead in paint, then paint samples need to be sent to an accredited laboratory for analysis. A listing of laboratories in Canada which are accredited to carry out testing for lead in paint can be obtained from the Standards Council of Canada or the Canadian Association for

Environmental Analytical Laboratories. Occupational health and safety regulations may specify the tests and procedures required. These laboratories usually use atomic absorption spectrometry (AAS) or inductively coupled plasma atomic emission spectrometry (ICP-AES) to analyse samples for lead. The results may be reported as milligrams of lead per kilogram of paint (mg/kg), micrograms of lead per gram of paint ( $\mu\text{g/g}$ ), parts per million (ppm), or as a percentage of lead by weight (weight percent, wt%). A concentration reported as 500 ppm lead, for example, corresponds to 0.05 wt% lead, 500 mg of lead per kilogram of paint, or 500  $\mu\text{g}$  lead per gram of paint.

When dealing with paint in historic houses or industrial sites, all paint colours should be sampled, and each sample must include all layers of paint. During sampling, the substrate below the paint should be avoided because its presence can reduce the lead concentration.

#### *On-site Testing*

When dealing with painted surfaces in historic buildings and at industrial sites, an environmental engineering consultant may be able to analyse the lead content in various painted surfaces *in situ* using X-ray fluorescence (XRF) equipment. A licensed operator is required to run the XRF equipment because of its radioactive source. Usually an average of three readings is taken for each area being sampled, with each reading taking about 15 seconds. A large number of surfaces can be analysed in a short time. It is possible to detect lead through many layers of paint without marring or discolouring the surface. Dense substrates such as concrete and metal (for example, lead-containing pipes) may affect the accuracy of the results. The most accurate readings are obtained when the machine is held against a flat surface, while less accurate values are obtained against curved, molded or textured surfaces. Portable XRF analysers are less accurate than laboratory analysis, but their use is favoured when evaluating a large number of painted surfaces.<sup>57</sup>

Results from XRF analysis are normally reported as milligrams per square centimetre ( $\text{mg/cm}^2$ ). Parks and Hicks report that a lead level in paint above  $1 \text{ mg/cm}^2$  (as determined by XRF) is considered a hazard.<sup>110</sup> They recommend that when lead levels are between 0.5 and  $1.5 \text{ mg/cm}^2$ , further laboratory analysis of paint samples be done to confirm XRF measurements (because this range is close to the limit of detection for lead by XRF). In order to compare results between laboratory analysis and XRF, a paint sample should be taken from a spot previously analysed by XRF and the laboratory requested to analyse the total weight of lead in the sample per unit of surface area for comparison purposes.

#### *Chemical Spot Tests*

Chemical spot tests are quick, relatively inexpensive, and are generally carried out to determine if lead is present at an elevated concentration. Their disadvantages are that they are qualitative and can be less sensitive than the other methods discussed previously, and they can give variable results. These tests do not determine how much lead is present and they are not always

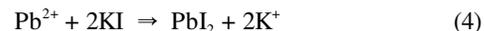
reliable. If in doubt, further testing must be carried out.

Chemical spot tests can be used to test for the presence (or absence) of lead in paint as well as in other materials such as pottery glazes, metals, and even in drinking water. These tests can be purchased as a commercial lead test kit or prepared in-house using the appropriate chemicals. Chemical spot tests rely on the ability of lead to combine with a chemical reagent to form a coloured product. In order for the chemical to react and change colour, lead must be present in the solution as lead ions (from corroding lead metal or from dissolving lead compounds). The colour change is usually obvious at higher lead levels, but becomes more difficult to see as the lead level decreases. Several lead test kits are sold for home use; these are often available in local paint, hardware, or drug stores.

The colour changes are usually easy to see unless the colour of the surface being tested is similar to that developed during the test. The spot test kits for home use typically include a swab or dropper that allows the chemical reagent to be applied to a surface, and the colour changes if lead is present in the range of 1–2 wt%, although some tests may be more or less sensitive. Because the specific chemical in the spot test only reacts with lead on the surface, it is important to cut, scrape or sand through the paint to expose each layer for testing.

Three chemicals are commonly used in spot tests for detecting lead: potassium iodide (colour change to yellow), sodium rhodizonate (colour change to pink through red), and sodium sulphide (colour change to brown through black). Their specific reactions are described below.

**Potassium Iodide:** The chemical spot test based on potassium iodide is used in conservation as well as for detecting lead in vinyl window blinds.<sup>27,79</sup> Lead ions dissolve in a potassium iodide solution and react to form thin yellow hexagonal plates of lead iodide, according to the reaction:



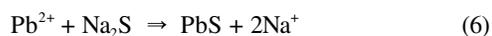
Reaction (4) is probably the basis for the D-Lead Test Kit for detecting lead.

**Sodium Rhodizonate:** Sodium rhodizonate reacts with lead ions and forms a reaction product with a colour ranging from pink to red. According to Feigl and Anger,<sup>118</sup> the underlying reaction is:



The end product is a precipitate of basic lead rhodizonate, the form and colour of which depends on the pH. In neutral solutions, the compound is a violet-coloured salt, and in weakly acidic solutions, the compound is a scarlet-red salt. The colour change can be difficult to see if testing a red surface, and sulphates (from gypsum or plaster) can interfere with the colour development. Reaction (5) is probably the basis for Plumbtesmo lead test paper and for some home-use spot test kits for lead (Lead Alert Kit, LeadCheck Swabs).

**Sodium Sulphide:** When a drop of a solution containing sodium sulphide is placed on a surface containing lead, such as a paint chip or a ceramic glaze, the surface turns black as lead sulphide forms, as given by:



Based on field experience, there is considerable confidence in a sodium sulphide spot test for testing for lead in paint.<sup>11</sup> However, there are several elements that can contribute to false positive results if present in sufficient concentrations and suitable chemical forms; these include copper, cobalt, mercury, manganese and iron, which also turn black in the presence of sulphide ions. The colour change can be difficult to see if testing on a dark surface. Reaction (6) is probably the basis for some home-use spot test kits for lead (The Lead Detective, Lead Inspector).

### Materials

D-Lead cleaning products: Esca Tech, Inc., 3747 North Booth Street, Milwaukee, WI 53212 U.S.A., (414) 962-5323. <[www.esca-tech.com](http://www.esca-tech.com)>.

Home-use lead testing kits (e.g., D-Lead Test Kit, Lead Alert Kit, LeadCheck Swabs, The Lead Detective, Lead Inspector): local pottery suppliers, paint stores, hardware stores or drug stores.

Ledizolv lead-specific detergent: LSZ, Inc., 9 East 40th Street, Suite 201, New York, NY 10016 U.S.A., (212) 684-9641. <[www.ledizolv.com](http://www.ledizolv.com)>.

Plumbtesmo lead test paper; made in Germany by Macherey-Nagel <[www.mn-net.com](http://www.mn-net.com)>; distributed in Canada by Aldert Chemicals, 4889 Dundas Street West, Suite 5, Islington, ON M9A 1B2, (416) 236-4222 or 1-800-268-6656.

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