

Appendix 1: Units of Measure Used in the Lead-Based Paint Field

Many of the units, terms, and concepts used in these Guidelines are new to the users. Most of the measures cited are in the Metric System of measure, rather than the English System that most people in the United States use on a daily basis. For this reason, a brief discussion of the most important concepts will be helpful to the user to develop a feeling for the quantities and terms used.

Terms and Definitions

An atom is one of the smallest units of matter, identifying a specific element. Lead is an element and is composed of atoms of lead; each lead atom behaves the same way when it interacts with other atoms. A molecule is a cluster of bound atoms which behave as a unit when interacting with atoms or other molecules. Materials made up of molecules are called compounds. The chemical and physical properties of compounds are unlike those of the elements which are present in them. Lead oxide, lead chromate, and lead acetate are all molecules formed when lead atoms combine with atoms of other elements to form molecules. These molecules are called lead compounds or sometimes lead salts. Lead acetate is a lead compound which has a sweet taste and is called "sugar of lead."

An electron is a negatively charged particle that orbits the positively charged nucleus of the atom. Every element requires a different number of electrons to neutralize the atom's positive nuclear charge. If an electron is removed from an atom then the atom becomes positively charged and is called an ion.

An X-ray is a type of high energy electromagnetic radiation. Heat and light are other forms of electromagnetic radiation. Atoms of a particular element emit a characteristic set of X-rays when excited. No two elements emit identical sets of X-rays. The unit of energy we use in talking about X-rays is the kiloelectron volt (one thousand electron volts), abbreviated keV. Lead "K" X-rays have energies between 72 to 87 keV. A gamma ray is electromagnetic radiation which is emitted from the nucleus of a radioactive atom. Most gamma rays emitted by radioactive Cobalt 57 have an energy of 122 keV, more than enough energy to interact with lead atoms in paint and produce lead "K" X-rays. A 122 keV gamma ray will penetrate through many paint layers and into the substrate. Lead "K" X-rays can also penetrate many layers of paint and even through some walls or doors.

Mass Units

Large units of mass and their abbreviations:

Gram (g or gm): A unit of mass in the metric system. A nickel weighs about 1 gram. A gram is equal to about 35/1000 (thirty-five thousandths of an ounce. Another way to think of this is that 28.4 g are equal to 1 ounce.

Kilogram (kg): The prefix "kilo-" means "1000 times". A kilogram is a unit of mass in the metric system that refers to 1000 grams or about 35 ounces. 35 ounces is about 2.2 pounds. 454 g are equal to 1 pound.

Small units of mass and their abbreviations:

Milligram (mg): The prefix "milli-" means "1/1000 of" (one thousandth of). A milligram is 1/1000 of a gram or about 35/1,000,000 (thirty-five millionths) of an ounce. 28,400 mg are equal to 1 ounce.

Microgram (μg): The prefix "micro-" means "1/1,000,000 of" (one millionth of). A microgram is 1/1,000,000 of a gram or 1/1000 of a milligram. A microgram is equal to about 35/1,000,000,000 (thirty-five billionths) of an ounce. 28,400,000 μg are equal to 1 ounce.

Length Units

Large units of length and their abbreviations:

Meter (M): A meter is a metric unit of length equal to about 39.37 inches, which is 3 and 37/100 of an inch longer than a yard.

Decimeter (dm): The prefix "deci-" means "1/10 of". A decimeter is 1/10 of a meter. Another way to say this is that one meter will contain 10 decimeters. A decimeter is about 3.937 inches.

Centimeter (cm): The prefix "centi-" means "1/100 of". A centimeter is about 39/100 of one inch. 1 inch contains about 2.54 centimeters.

Small units of length:

Millimeter (mm): The prefix "milli-" means "1/1000 of". There are 1000 mm in 1 M. There are 10 mm in 1 cm. 25.4 mm equals 1 inch.

Micrometer (μm): The prefix "micro-" means "1/1,000,000 of". There are 1,000,000 μm in 1 M. There are 1000 μm in 1 mm and 10,000 μm in 1 cm. The term micron is also used interchangeably for μm . There are 25,400 microns is 1 inch.

Nanometer (nm): The prefix "nano-" means "1/1,000,000,000 of" (one billionth of). A meter can be divided into 1 billion nanometers. The wavelength of the light that is visible to us is in the range from about 350 to 700 nanometers; 450 nm is the wavelength of blue light; 550 nm, green light; 650 nm, red light. X-rays have much shorter wavelengths than visible light because they have more energy.

One more small unit encountered in discussing paint films is not a Metric unit but an English unit. The unit that paint film thicknesses are usually measured in is the "mil". A mil is equal to 1/1000 of one inch. A 2 mil paint film per coat is considered average,

assuming that the paint contains about 50% solids and has a spreading rate of 400 ft²/gallon. This would correspond to a paint film thickness of about 50 µm for a single coat of paint. 1 mil is equal to about 25.4 microns. Plastic films are also measured in mil.

Conversion to Areas and Volumes

An area is a measure of the length times the width of some object. The area is expressed as a "square unit" (2). Square feet (ft²) is an area unit. Similarly, in the metric system we can have square meters (M²) or square centimeters (cm²).

$$\begin{aligned}1 \text{ ft}^2 &= 929 \text{ cm}^2 \\1 \text{ square cm} &= 1 \text{ cm}^2 \\1 \text{ square inch} &= 1 \text{ in}^2\end{aligned}$$

The volume is a measure of an area times a height of a cylindrical object. The volume is expressed as a cubic unit (3) such as a cubic foot (ft³). A liter is a metric unit of volume equivalent to 1000 cm³ or 1000 cubic centimeters, abbreviated cc. A milliliter is 1/1000 of a liter and is abbreviated ml. The terms cm³, cc and ml are used interchangeably to refer to small liquid volumes. In the English System we use quarts, gallons, etc., as volume measures. A liter is equal to 1.057 quarts.

Concentration Units

Weight per cent or % by weight (%w/w): The weight of lead in some mass unit per 100 weights of the total sample (in the same mass units). For example, if a 1 gram paint sample contains 0.1 g of lead, then the paint is 10.0% lead by weight (w/w). Also, 1 ounce of lead in 10 ounces of paint is 10% w/w lead. All weight per cent measurements refer to the dried paint film.

Parts per million (ppm): The weight of lead per 1,000,000 weights of the total (including lead) sample. For example, if a paint sample contains 5,000 µg of lead in 1 g of paint, then the lead concentration is 5,000 PPM or 0.5% w/w.

Area concentration: A mass of lead per unit area of the total paint sample, sometimes called "loading". This is independent of the volume (or thickness) of the paint sample. This unit is encountered in measuring paint by portable X-ray fluorescence instruments and laboratory techniques. The HUD regulatory level is 1.0 mg/cm² or 1000 µg/cm². Area concentration (loading) is also used to describe settled leaded dust levels in µg/ft² (micrograms of lead per square foot of surface area). 200 µg/ft² equals 1.85 mg/m² (milligrams of lead per square meter).

One cannot convert from ppm or % by weight to area concentration (mg/cm²) as measured by an X-ray fluorescence instrument in any predictable way unless the total mass per unit area of the sample is known. One reason is that the dilution factor of adding more non-leaded paint layers over an existing leaded one will not change the area concentration. However, adding additional layers of paint will change the % by weight. The area concentration is independent of the thickness of the paint layers. The XRF determines the lead mass per unit area as measured by X-ray emission from a lead layer (mg/cm²). The weight percent method measures the percent

of lead in the bulk paint films by determining the weight of lead in the total paint sample.

Consider the case of many layers of paint each containing 0.5% lead by weight. The theoretical concentration limit for all the layers together cannot exceed 0.5% but if (about) 20 or more layers are present then the corrected XRF response may indicate 1.0 mg/cm² or higher. The 1 mg/cm² regulatory level is, in this case, a more stringent standard than the 0.5% standard. Conversely, consider the case of a leaded paint layer with 10% lead by weight. If another layer of non-leaded paint of the same thickness and density is added to the leaded paint layer, the concentration of both layers together would be: 10%/2 layers=5%.

Also, one cannot convert ppm in leaded dust to loading (µg/ft²) unless the total weight of the dust is known. The total weight of dust cannot be determined by wipe sampling.

Some examples will serve to illustrate the concepts and quantities indicated in the previous discussion.

If we assume that a gallon of paint (12 lbs/gallon) having almost 50% solids and 12% lead is applied over 400 square feet, the area lead concentration would be

$$\frac{(0.5)(0.12)(12 \text{ pounds/gallon})(1000 \text{ mg/g})}{(400 \text{ ft}^2/\text{gallon})(2.54 \text{ cm/in})^2 (12 \text{ in/ft})^2 (0.0022 \text{ pounds/g})} = 0.88 \text{ mg/cm}^2$$

This example illustrates that, in theory, 1 mg/cm² corresponds to a lot of lead in a single layer of paint (about 12% lead). Because of the presence of many layers of paint in target housing, on average 1 mg/cm² is about equal to 1% lead.

To conceptualize quantities of lead in paint we can make some reasonable assumptions. If one assumes a lead pigment particle size of about 1 mm in diameter, and that the particles are about the size of grains of salt (but heavier) and that one of these pigment grains weighs about 30 µg, only about 30 of these grains distributed in an area of 1 cm² will be required to give an area concentration near 1 mg/cm². The lead pigment particles will actually occupy only a small fraction of the total 1 cm² area. This small amount will usually be visible to the eye, under conditions of good light and contrast, on an abated surface, if present as a post-abatement residue.

Can painting over leaded dust create a lead-based paint? While one could conceivably apply the definition of lead-based paint (5,000 ppm) and assume a certain thickness in the new paint film to calculate the weight concentration of lead in the new paint film from the dust loading in µg/ft², the result is well above the dust clearance standards. Consider the following example: If, after treatment, 35,000 µg/ft² of leaded dust remains on the surface, and it is painted over with a lead-free new paint at a rate of 400 ft²/gallon with a density of 12 lbs/gallon and 50%

solids by weight, the total weight of the paint solids per unit area is 7.3 mg/cm². Thus, the weight percent concentration of lead in the new paint film would be about 5,000 ppm:

$$\frac{(12 \text{ pounds/gallon})(0.5)(0.488 \text{ g/cm}^2 / \text{pounds/ft}^2)(1000 \text{ mg/g})}{400 \text{ ft}^2/\text{gallon}} = 7.3 \text{ mg/cm}^2$$
$$35,000 \text{ } \mu\text{g/ft}^2 (0.001 \text{ mg/}\mu\text{g}) (1 \text{ ft}/12 \text{ inches})^2 (1 \text{ inch}/2.54 \text{ cm})^2 = 0.038 \text{ mg/cm}^2$$
$$\text{ppm by weight} = \frac{0.039 \text{ mg/cm}^2}{7.3 \text{ mg/cm}^2} \times 1,000,000 = 5,200 \text{ ppm}$$

Since the current HUD standard for lead-based paint is 5,000 ppm (0.5%), this means that the new lead-free paint would become lead-based paint. However, it is extremely unlikely that 35,000 $\mu\text{g/ft}^2$ would be found on stripped surfaces if the surfaces have been stripped and cleaned adequately.

If one relied on XRF testing to determine lead contamination of surfaces where the lead paint had been removed, it would almost certainly be necessary to correct for substrate effects, since the readings would probably be quite low. If some of the lead did soak into the substrate during the removal process, determination of the true substrate effect would be quite difficult, if not impossible. Current XRF instruments have detection levels well above 0.038 mg/cm².

The diameter of a lead particle found in paint will be on the order of 0.1 to 10 micrometers (μm). Scraping, sanding, and heating lead-based paint will result in the formation of small particles. These particles are usually much smaller than the salt grain examples used above. These very small particles actually float in the air and can be inhaled as we breathe. Very small particles do not settle very rapidly. For this reason very stringent worker protection and clean-up measures are needed for lead hazard control work in lead-based paint abatement.

Heat gun removal at temperatures below 1,100°F will not melt and vaporize lead into the air. It could, however, produce paint "soot" particles from the paint film which will trap the tiny lead particles and allow them to become airborne. Welding and open flame burning temperatures melt and vaporize lead compounds in paint; these temperatures are much higher than those generated by heat guns.

Biological Quantities of Lead in Lead-Based Paint

Blood lead levels are expressed in micrograms of lead (μg) per deciliter of blood (dl). A deciliter is one tenth of a liter. Blood lead levels are reported in $\mu\text{g/dl}$. A child can eliminate approximately 5 micrograms of lead for each kilogram of body weight in one day. If a ten kilogram (22 lb) child ingested a paint chip containing 1.0 mg of lead, that child would ingest approximately 20 times more lead than could be eliminated by his body in one day (assuming that the digestive system were able to digest the entire paint chip). If we allow that only 10% of the lead in the paint chip is absorbed into the child's body then the child would still ingest twice as much lead, from one paint chip, as his body could eliminate in 24 hours.

Dr. Julian Chisholm in "Lead Based Paint in Housing", National Institute of Building Sciences LBP Task Force Report, February 20, 1988, pp. 23-24, writes:

Experimental and human data indicate that chronic average daily ingestion of lead of 16.8 $\mu\text{g Pb/kg}$ of body weight or 168 $\mu\text{g Pb/day}$ in a 10 kg child from paint could raise blood lead concentrations from 20 to 54 $\mu\text{g/dl}$.

Currently, the definition of an elevated blood lead level in children is 10 $\mu\text{g/dL}$.