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author: Harold P. Vind, C. W. Mathews,
R. L. Alumbaugh, and G. W. Hamilton

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CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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The Civil Engineering Laboratory investigated ways to implement the Lead-Based Paint Poisoning Prevention Act (LBPPPA) in Navy housing. According to the act, cracked or peeling paint must be wire-brushed before repainting. There appears to be no pre-repainting requirement for the removal or covering of lead-based paint that is sound and tight, unless the integrity of the paint cannot be maintained. The maximum concentration of lead permitted in new paint is 0.06%. An inexpensive chemical kit (continued)

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CONTENTS

INTRODUCTION: DETECTION AND REMOVAL OF LEAD-BASED PAINT

The Lead-Based Paint Poisoning Prevention Act (LBPPPA) of 1971 (Ref 1) authorized grants to carry out comprehensive testing programs to detect the presence of and to eliminate lead-based paint from surfaces of residential structures accessible to children. Underlying lead-based paint, even if covered by several layers of nonleaded paint, was also to be removed. The amendments of 1973 (Ref 2) directed the Department of Housing and Urban Development (HUD) to develop methods for detecting and removing lead-based paint. Other amendments followed (Ref 3 through 9).

NAVFAC* Instruction 10365.2A of 12 February 1975 (Ref 10) directed Navy activities to comply with the provisions of the LBPPPA. The instruction stipulated that no lead-based paint be "applied on residential structures where these paints might constitute a hazard to the occupants." The instruction further stipulated that

> "since paint previously applied on residential structures may constitute a hazard to the occupants in some instances, the lead content of the existing paint should be determined in those instances, before repainting is done. If the lead content exceeds the regulatory limit, that paint should be removed."

HUD sponsored a continuing study of the problem of lead-based paint at the National Bureau of Standards (NBS). However, when NAVFAC issued Reference 10 no completely satisfactory field methods existed for determining the lead content of paint nor for removing or covering lead paint once it had been discovered.

So that the lead-paint hazard in Navy housing might be expeditiously eliminated, NAVFAC initiated and sponsored the Civil Engineering Laboratory (CEL) in an investigation of practical methods for detecting and removing lead-based paint. This report describes the CEL study, conducted in Fiscal Years 76 and 77 and reviews the LBPPPA.

Recent amendments to the LBPPPA that went into effect 22 June 1977 (Ref 7) and 28 Feb 1978 (Ref 8 and 9) eliminate the necessity for field instruments or kits for detecting lead-based paint, but the use of such equipment remains highly desirable. The amendments do not require removal or covering of old layers of lead-based paint that are not cracked or peeling, unless the integrity of the paint cannot be maintained. Irrespective of its lead content, cracked or peeling paint must be brushed, scraped, or otherwise removed from the surface. Two coats of unleaded paint should then be applied. The maximum lead concentration permitted in new paint is 0.06% by weight in the dried film.

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*Naval Facilities Engineering Command.

HAZARDS OF LEAD-BASED PAINT

When paint degrades or peels from buildings, children, especially those who are teething, frequently ingest it (Ref 11). Teething children also frequently ingest paint by chewing on the surfaces of window sills, door frames, furniture, or toys. They may be poisoned by the paint if it contains lead.

Levels of Lead Poisoning

Acute lead poisoning is characterized by sudden onset, coma, and convulsions (Ref 12 through 15). The onset is followed by such diverse afflictions as paralysis, severe mental retardation, blindness, nephritis, anemia, colic, or death. Prompt application of chelation therapy reduces the mortality of acute lead poisoning but does not ameliorate the other aftereffects.

Chronic lead intoxication is characterized by a steady buildup of the metal in the victim's blood. This may cause severe disorders of the digestive system, liver, kidneys, or nervous system. Relatively low accretion in the blood can cause shaking, reduced eye-hand coordination, stomach trouble, insomnia, and loss of teeth. Milder chronic lead intoxication can cause emotional changes such as hostility, depression, and generalized unhappiness.

In addition to the danger of acute and chronic lead poisoning, the effect of trace amounts of lead on learning ability and emotional behavior are also of considerable concern. Recent screening programs reveal that 5% to 10% of young children in the United States have high enough concentrations of blood lead to detectably alter hemoglobin synthesis. In view of the large number of children involved, the mere threat that this might slightly reduce their learning speed or alter their emotional behavior is of grave concern.

The mildest detectable adverse effect of lead ingestion is derangement of hemoglobin synthesis (Ref 16 and 17); lead blocks the synthesis of heme. Zinc protoporphorin, a precursor of heme, then accumulates in the blood. When irradiated with light from the blue end of the visible spectrum, zinc protoporphorin fluoresces with a characteristic red light, and mere traces can thereby be detected. Early detection of lead poisoning is now based on a fluoroscopic examination of a drop of blood. Although slight derangement of hemoglobin synthesis is not followed by the symptoms of acute or chronic lead poisoning, considerable evidence shows that it does slightly alter learning capacity and mental behavior.

Occurrence of Acute Lead Poisoning

According to NBS (Ref 18), 12,000 to 16,000 children succumb to acute lead poisoning in the United States annually. An estimated 200 of them die; the others suffer permanent brain damage, go blind, or become mentally retarded hospital patients. A small fraction of these lead-poisoning cases may occur among children living in Navy housing.

Nearly all of the instances of acute lead poisoning in the United States for the past few decades were caused by lead-based paint. Most of them occurred among children in the 1- to 6-year age bracket. Over 50% of all deaths from lead poisoning occur in teething 2-year-olds (Ref 19). Not all of the intake of lead by children is in the form of lead-based paint, but the quantities obtained from the other sources are rarely sufficient to cause acute poisoning.

Most of the instances of acute lead poisoning of adults from occupational exposure to lead also result from lead-based paint (Ref 20). Painters, workers engaged in the manufacture of paints and pigments, and workers engaged in scrap metal salvage and shipbreaking frequently succumb to acute lead poisoning. The source of the hazard in the shipbreaking and scrap-salvage operations is lead-based paint used to protect the iron and steel from rusting. The heat of the cutting torches oxidizes the lead into hazardous fumes breathed by the worker.

Though statistics do not appear to be available to substantiate the statement, it is reported that pediatricians familiar with the problem agree that the incidence of acute lead poisoning has decreased substantially during the past decade. This is in spite of the fact that there have probably been no great changes in the amount of lead-based paint the children and salvage workers are exposed to or in the kind of therapy employed. Lead-based paints for use on residential structures have presumably not been sold since 1971, but very little of the previously applied paint has been removed and stocks of previously manufactured paint were used after 1971. It would appear that the marked reduction in the number of deaths from lead poisoning is primarily from a great increase in the awareness both by the physician and the parent as to the great danger of lead-based paint.

Chronology of The Use of Lead Paint

Paint from homes constructed before World War II is usually blamed for acute lead poisoning of teething children, but at least some of the paint on nearly all of the residential structures in the United States contains sufficient lead to cause acute or chronic poisoning if ingested over a period of time.

Prior to World War II, white lead was the basic hiding pigment employed in oil-based paints; water-based latex paints did not exist. After the war, titanium dioxide gradually replaced white lead because of its superior hiding power. It was cheaper to employ because less was required. The all-white lead paints have seldom been used since the war, but paints with pigment blends containing some white lead were commonly used until about 1972. Yellow-, green-, and red-lead pigments were also frequently used in enamels and primers until about 1972. Red lead is still widely used in industrial coatings to prevent the corrosion of iron and steel, but no lead compounds are now permitted in architectural coatings for residential structures.

Lead Paint Hazard in Navy Housing

NBS conducted a very brief survey of the lead-based paint poisoning hazard in selected pre-1950 dwelling units in Navy family housing at Boston, Mass. (Ref 21). In one of the apartments a 2-year-old child had removed and eaten all of the paint from an area of the bedroom wall in excess of 1 sq ft. Fortunately, the paint contained mere traces of lead, if any. However, exterior wooden surfaces on each of the four buildings inspected contained some peeling paint with a high lead content. Paint with a moderately high lead content was found on interior bathroom and kitchen walls. A potential lead paint poisoning hazard clearly existed.

Conclusions

Though greatly reduced in number, deaths and other serious consequences of acute lead poisoning have not yet been eliminated. The need for stringent regulations to prevent the exposure of young children to lead-based paint still exists.

LEAD-BASED PAINT POISONING PREVENTION ACT

To provide financial assistance for various local, state, and national programs for the prevention of lead-based paint poisoning and to prohibit future use of such paint on federal or federally assisted residential construction, Congress passed Public Law 91-695 of 1971 (Ref 1). The act was revised and amended by Public Laws 93-151 (Ref 2) of 1973 and 94-317 (Ref 3) of 1976. As directed by the act, HUD proposed a series of rules and regulations to implement the provisions of the act (Ref 4). After public hearings (Ref 5) and various studies and surveys, the rules and regulations were revised (Ref 6) and amended (Ref 7). The Consumer Product Safety Commission (CPSC) also issued a series of rules and regulations (Ref 8 and 9) implementing the LBPPPA. Some rules and regulations applicable to the Navy are summarized or excerpted in the following paragraphs.

Rules and Regulations Issued by HUD

"Lead-based paint," as defined in the amended act, means any paint having a lead content greater than 0.5%, if the paint was manufactured before June 23, 1977, or any paint having a lead content greater than 0.06%, if it was manufactured after that date. The lead content is calculated as the percent by weight of lead metal in the dried paint film or in the nonvolatile constituents of the liquid paint.

"Residential structure" means any house, apartment or structure intended for human habitation, including any institutional structure where persons reside. Family housing, officers' quarters, barracks, bachelor quarters, dormitories, and hospitals all fit the description. Community facilities, which would presumably include cafeterias, are also included.

"Applicable surfaces" means all interior surfaces, whether accessible or not, and those exterior surfaces such as stairs, decks, porches, railings, windows, and doors that are readily accessible to children under 7 years of age.

"Immediate hazard" means paint (which may contain lead) on applicable surfaces which is cracking, scaling, chipping, peeling or loose.

"Defective paint condition" means any paint on applicable surfaces cracking, scaling, chipping, peeling, or loose.

The use of lead-based paint is prohibited in the maintenance and construction of all residential structures erected by or for the Navy or any other Federal agency. Appropriate provisions prohibiting use of lead-based paint must be made in all contracts and subcontracts for constructing or rehabilitating such structures. Provisions must be included for enforcing that prohibition.

Prior to occupancy, federally constructed residential structures must be inspected to ascertain the condition of the paint. Defective paint conditions shall be assumed to be immediate hazards. Surfaces identified as immediate hazards shall be thoroughly washed, sanded, scraped, wire-brushed, or otherwise cleaned so as to remove all cracked, scaling, peeling, chipping, and loose paint on applicable surfaces and then repainted with two coats of nonleaded paint. Where paint integrity cannot be maintained, the paint shall be completely removed or the surface covered with suitable material such as gypsum wallboard, plywood, or plaster before any repainting is undertaken.

Federal agencies will comply with state or local laws, ordinances, codes, or regulations regulating lead-based paint-hazard abatement, except that the Federal standard for lead content in paint supersedes any state or local requirements.

Purchasers and tenants of federal housing constructed prior to 1950 shall be notified (1) that the property was constructed prior to 1950, (2) that the property may contain lead-based paint, (3) of the potential and immediate hazards of lead-based paint, (4) of the symptoms and treatment of lead-based paint poisoning, and (5) of the precautions to be taken to avoid lead-based paint poisoning, including maintenance and removal techniques for eliminating such hazards.

Rules and Regulations Issued by CPSC

In the most recent amendments (Ref 8 and 9) to the LBPPPA, CPSC issued further rules and regulations pertaining to the lead content of coating materials for consumer products. Paint and other coating materials having a lead content greater than 0.06% by weight of the nonvolatile constituents are banned as items of commerce. Furniture, toys, and other children's articles are also banned if they bear coatings having a lead content in excess of 0.06%. The new regulations became effective 28 February 1978 and apply to all products manufactured after that date. Until that time, products covered by the regulations were subject to the previously existing 0.5% limit.

Some specialty coatings are specifically exempt from the rules and regulations pertaining to lead content, providing warning labels are used. Included in this category are the following consumer products: (1) agricultural and industrial equipment refinish coatings, (2) industrial (and commercial) building and equipment maintenance coatings, including traffic and safety marking coatings, (3) graphic art coatings (i.e., products marketed solely for application on billboards, road signs, and similar uses and for identification marking in industrial buildings), (4) touch-up coatings for agricultural equipment, lawn and garden equipment, and appliances, and (5) catalyzed coatings marketed solely for use on model radio-controlled, powered aircraft.

The National Paint and Coatings Association (NPCA) had also requested exemptions for exterior rubber-based roof coatings and for exterior primer coatings for redwood and cedar. CPSC denied the requests because such coatings might be available to children and nonleaded substitutes are readily available.

Automotive refinish and touch-up coatings and exterior marine coatings for small craft application are completely excluded from the banning operation. Such products are outside of the statutory definition of "consumer product" and are therefore not within the jurisdiction of CPSC.

METHODS FOR DETECTING LEAD-BASED PAINT

Three methods for detecting lead in paint were studied by CEL: (1) sodium sulfide reagent, (2) beta-ray backscattering gages, and (3) an x-ray fluorescence analyzer. Variations of these detection methods are discussed in the following sections. Coatings containing known amounts of lead were prepared and applied to various substrates to test the detection methods.

Preparation of Painted Reference Panels

Reference coatings or mock paints containing various quantities of lead were prepared from cellulose acetate, titanium dioxide, lead carbonate, and acetone. In each paint, cellulose acetate composed 40% and pigment 60% of the nonvolatile weight. Mock paints having lead contents of 0.0, 0.1, 0.5, 2.5, 12.5, and approximately 50% of the nonvolatile weight were prepared. Sufficient quantities of acetone were added so that the mixtures could be conveniently applied by brush to small wooden panels. The panels, approximately 1/2-inch thick, were cut into 1-inch squares. These were subsequently used for evaluating spot test reagents at CEL.

Another series of coatings prepared in the same manner were applied to small panels of various materials: wood, tinned steel, plaster-of-paris, and commercial paper-covered plasterboard. These panels, 4 to 6 inch squares or 4 inch circles, were prepared primarily for evaluating various instrumental analyzers for lead paint. The cellulose acetate binder did not adhere well to the tinned steel so another series of coatings were prepared with rosin instead of cellulose acetate. The rosin binder coatings adhered sufficiently well for the purpose. In each case, only one coat of the reference coating was applied. The panels were weighed before they were painted and again after the paint had dried to constant weight. Thus, both the weight and the lead content of the coatings were known.

Another series of wooden panels were painted with titanium dioxide paint containing less than 0.5% lead or with titanium dioxide paint to which sufficient lead carbonate was added to produce a paint with a lead content of 5% by weight. The panels were covered with 1, 2, 4, 6, or 8 coats of the reference coatings, which were applied by brush. Before and after each coat was applied, the panels were dried to constant weight.

Sodium Sulfide Reagent

Initial Studies. An inexpensive and easily used reagent for detecting lead in paint was developed at the University of Rochester, New York (Ref 22 and 23). A drop of an aqueous sodium sulfide solution (5% to 8%) was placed on a chip of paint. Layers of paint that contained lead turned black or gray; the greater the concentration of lead, the darker the gray. The Navy has employed this reagent in a kit for identifying samples of weathered paint in the field (Ref 24 and 25).

The sodium sulfide reagent was modified at CEL so that it could be applied directly to walls and even to ceilings without having to scrape chips of paint from them. A thickener was added to the reagent to enable it to adhere better to walls and ceilings. Small quantities of special solvent were also added to the reagent to enable it to better penetrate the paint film.

It is known that sodium sulfide in aqueous solution slowly hydrolyzes, forming hydrogen sulfide and sodium hydroxide. The hydrogen sulfide escapes as a gas, and the sodium hydroxide remains dissolved but does not react with lead compounds to form a black sulfide.

A shelf-life study was initiated to determine how long a sufficient quantity of sulfide would remain to produce color on contact with lead-containing paint. Both thickened and unthickened reagents were prepared for the study, each at approximately 3% and 10% sodium sulfide concentrations. Three small portions of each of the four reagents were placed into individual 15-ml dropping bottles and stored at temperatures of 35^o, 20^o, or 5^oC. Periodically, aliquots of the reagents were tested for residual sulfide. An iodometric procedure involving back-titration with sodium thiosulfate solution and starch indicator solution was employed.

The results of the shelf-life study are summarized in Table 1. They show that hydrogen sulfide escapes at a relatively constant rate over a wide range of concentrations of sodium sulfide. Hence, the shelf life of the reagent is roughly proportional to the initial concentration of sodium sulfide. A 10% reagent should be useful for a year even without refrigeration, but storage at 5°C is recommended.

CEL Lead-Detecting Kits. A "vest pocket" lead-in-paint detector kit (Figure 1) was developed at CEL for use at Navy field activities. Each kit contains a 15-ml dropping bottle filled with the modified sodium sulfide reagent, a sharpened nail, a few cotton-tipped applicator sticks, and a few strips of lead acetate paper for testing the sensitivity of the reagent.

The reagent can be applied to a painted surface or to a paint chip either directly from the dropping bottles or with clean cotton-tipped applicator sticks. Even though the reagent contains paint remover solvents, it will not penetrate underlying layers of paint and primer coats. Therefore, the sharpened nail should be used to scribe a pair of 1/2-inch-long crossed scratches completely through the paint to the underlying substrate. The reagent can be applied at the point of intersection of the scratches. The effect of the reagent on all layers of paint can then be observed.

The lead-in-paint detector kit is especially useful for determining whether a newly applied layer of paint complies with the restrictions on lead content. X-ray instruments cannot do this because they respond to the lead in the underlying layers as well. The kit can also be used to determine whether the underlying layers of paint constitute a lead-poisoning haza d, and x-ray instruments can supplement the examination.

Convenie ly, the minimum amount of lead detectable with the kit is approximately 0.5% (Figure 2) which, until recently, was the maximum amount allowable by Federal law. The maximum legal limit is now 0.06%, but the 0.5% limit still applies for paint applied before 22 June 1977 (HUD regulations) and 28 February 1978 (CPSC regulations). The kit is not quite sensitive enough to detect all paint with a lead content between 0.06% and 0.5%, but it will detect all paint with a lead content grossly exceeding the legal limit. With a hand lens it is sometimes possible to detect lead in paint at slightly below the 0.5% level.

The small quantity of sodium sulfide reagent contained in the kits is no more dangerous to handle than an equivalent amount of diluted lye water. Nevertheless, it is strongly alkaline and should be kept out of the eyes and mouth and out of the reach of children. Skin irritation is minimal, but the reagent will cause chapped hands if not promptly washed off with water.

Arrangements were made for the Koslow Scientific Company of North Bergen, N. J., to manufacture and stock the lead-in-paint detector kit. CEL purchased a number of the kits for distribution to Navy activities. Initial distribution was made to all Engineering Field Divisions (EFD) and Public Works Centers (PWC). CEL also distributed many kits to field personnel at Navy activities. For a limited period, CEL will continue to supply kits on requests from the field if approved by the EFD's Public Works Officers.

Beta-Ray Backscattering Paint-Thickness Gage

Beta-ray backscattering techniques have been used for measuring the thickness of different kinds of films on various materials. Some practical applications have been to measure the thickness of tin plate on steel, metal coatings on plastic, and paints on paving materials (Ref 26, 27, and 28). In general, the number of beta rays that backscatter from a film increases with the thickness of the film up to some saturation backscattering range for the material. Work at CEL indicated (Ref 29) that beta-ray backscattering might be a useful technique for measuring paint-film thickness on wood.

CEL Study. CEL undertook the development and evaluation of an experimental, direct-reading, paint-thickness gage for paint films on wood (Ref. 30). The gage employed backscattering from a 1/4-microcurie strontium-90 radioactive source.

With the experimental gage, the intensity of the backscattering was proportional to film thickness for each of three military specification paints on wood. One of them was pigmented with a mixture consisting primarily of white lead (TT-P-102); the other two (TT-P-0055 and TT-P-19) were pigmented with titanium dioxide. The intensity of the backscattering per unit thickness of film was found to be greatest for the coating pigmented with white lead.

To test the method further, an attempt was made to measure the thickness of films of nonleaded paints applied over a lead-based primer coat (TT-P-25) on wood. The topcoats appeared to be transparent to the beta radiation, and the intensity of the backscattering was the same from the primer alone as from the primer on which four topcoats were applied.

Observing that the backscattering intensity was greatest for paints pigmented with lead compounds, CEL proposed that the paint-thickness gage might be better employed as an instrument for detecting lead paint (Ref 30).

During a field inspection of Navy housing near Boston (Ref 21), an opportunity came to test the CEL proposal. Several painted surfaces were tested with the CEL-proposed, beta-ray, lead-in-paint gage which can be assembled for well under $1,000. The same surfaces were tested with a commercial x-ray fluorescence lead-paint analyzer which cost nearly $5,000. The results, summarized in the following table, indicated that the readings on the prototype lead-paint gage proposed at CEL were related to the lead content of the paint.

Coatings Tested*	CEL Beta-Ray Gage (counts/min)	Gamma Tech X-Ray Meter (mg/sq cm of lead)
Bare wood	620	0
One coat paint with 1% lead content	720	0
Leaded paint on building exterior	2,800	6
Leaded paint on building exterior	2,900	8
Heavily lead-pigmented mastic	4,800	38

Naval Reserve Study at the Lawrence Livermore Laboratory. Naval Reserve Research Company 11-4 at the University of California's Lawrence Livermore Laboratory undertook evaluation of a gage for measuring the lead content in paint by backscattering of beta rays (Ref 31). The evaluation was performed on the prototype lead-paint gage** developed at CEL. The effort included both an in-depth theoretical and mathematical review of the potential of beta-ray backscattering in paint analysis and an empirical review of experimental data obtained with the prototype instrument.

The theoretical review confirmed some anticipated problems: (1) The backscatter signals cannot be distinguished from the substrate and the paint film; and (2) the backscatter signal is not specific for lead.

The first difficulty can be overcome by obtaining a reading from the bare substrate and subtracting that value from the reading on the painted substrate. Thus, the difference is an estimate of the backscatter signal from the paint film only. This estimate will be more accurate when the average atomic weight and density of the substrate is not great (as, for example, when the substrate is wood).

The second difficulty cannot be overcome as easily. The strength of the backscatter signal from the paint film is proportional to a function of the average atomic weight of the film. Thus, the backscatter signal from a given number of lead atoms will be considerably greater than the signal from the same number of titanium atoms. However, the signal from the titanium will not be insignificant. Backscattering from a thick layer of paint heavily pigmented with titanium dioxide may be as great as the backscatter from a thin coat of paint pigmented with a small amount of white lead.

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*All on wood substrate.

**The same as the paint thickness gage.

Theoretically, however, the instrument can still be used for screening purposes. The intensity of the backscatter signal from a reference paint film containing a given quantity of lead and applied to a given substrate such as wood is first established. In the field, painted surfaces on the same substrate that give higher readings are suspected of containing more lead than the reference coating.

Much more promising is a conversion from the high energy strontium-90 source to a low-energy carbon-14 source. The complications caused by the substrate would be eliminated since the low energy beta rays would not penetrate through the paint to detect the substrates. The measurement would yield the average atomic weight of the film but would be the same for thick or thin films. That is, the readings would reflect the percentage of lead in the paint but not the total quantity of lead per unit area.

Finally, considerable experimental data were obtained during the Livermore study. The data substantiated the theoretical predictions.

Beta-Ray Gage and Ratemeter. The prototype lead-paint gage discussed in the previous section of this report was designed for ruggedness and portability; plastic materials housed the Geiger-Müller tube and the 1/4 μcurie strontium-90 radiation source. The radiation source, covered with a brass shield when not in use, was mounted coaxially with the Geiger-Müller tube. A counting ratemeter was housed in a steel case; the gage and ratemeter are shown in Figure 3.

To improve portability and lower the price, the counting ratemeter was employed instead of a scaler. The counting ratemeter has disadvantages for measuring radioactive disintegrations which inherently fluctuate in frequency from one instant to the next. An experienced operator can average these fluctuations by eye, but the ratemeter is not an ideal instrument for the inexperienced because the readings are open to subjective decisions. In the next section of this report the same gages in combination with a scaler will be evaluated.

Two additional instruments were fabricated to CEL specifications by Technical Associates of Canoga Park, Calif. The two instruments were almost identical, but one of them was equipped with a 1 μcurie strontium-90 radiation source and the other with a 100-microcurie carbon-14 source. The carbon-14 instrument is shown in Figure 4. The 1975 price for the instrument was $775.

Readings on the reference lead-paint coatings were made with all three instruments. Two different observers made the readings, which were executed in random order, and the results are summarized in Table 2.

The paint films on the tinned steel could not be detected with beta radiation from strontium-90. The contribution to the backscattering signal by the metallic background was greater per unit thickness than that of the paint film, which tended to detract from, rather than enhance, the signal.

The average density and the atomic weights of the plasterboard, plaster-of-paris, and wooden substrates were all considerably less than the same parameters for the lead-pigmented paints. The intensity of the backscattering was increased by the paint. Estimates of the contribution to the signal by the paint films were made by subtracting the reading of the bare substrate from the reading of the painted substrate. In Figures 5 and 6, these values are plotted against the lead content of the paint film in milligrams per square centimeter. A correlation between the two values is apparent. The data of Figures 5 and 6 indicate that the strontium-90 gage and meter could be used for detecting paint films suspected of having lead contents greater than about 4 mg/sq cm. Although a lead content of 2 mg/sq cm gives a definite signal, it is likely to be overshadowed by errors in the correction for the substrate. In the field, extremely hazardous paint films with lead contents as great as 40 mg/sq cm are sometimes encountered. Hence, the strontium-90 instrument could serve as a screening instrument for locating especially hazardous lead-based paints on low density surfaces such as wood or plaster.

Carbon-14 beta rays backscattering from single layers of paint with a given percentage of lead had approximately the same intensity regardless of the nature of the substrate. Furthermore, backscattering from a surface covered with four layers of paint with a lead content of 5% was approximately the same as from a surface covered with only one layer. Obviously, radiation from the carbon-14 penetrated into the paint a distance of less than the thickness of one layer. In Figure 7 the backscatter readings were plotted against the lead content of the paint in percent by weight. From the plot it can be seen that the intensity of the backscattering is approximately proportional to a function of the percentage of lead in the paint and is unrelated to the quantity of lead per unit area. The carbon-14 instrument is well-suited for examining the outermost layer of paint, the layer most recently applied. However, the backscattering signal is not pronounced until the lead content of the paint reaches a value of at least 5%. As the legal limit is now 0.06%, such an instrument would not be too useful.

Beta-Ray Gage With Scaler. The two beta-ray backscattering gages assembled by Technical Associates, one with a strontium-90 and one with a carbon-14 radiation source, have been modified so they can be connected to a scaler. The same scaler, H.P.I., Inc., Model 1040, is employed for both instruments. It accumulates the number of voltage spikes caused by individual discharges in the Geiger-Müller tube over a pre-set length of time, thus acting as an integrator. The need to estimate the position of a needle is eliminated; the readout is a fixed digital number.

The scaler was set to give cumulative counts of beta-ray backscattering over 1/10-minute intervals. Readings were made with both instruments on the same set of reference coatings employed for evaluating the gages with ratemeter readouts. In this instance the sequence of the readings was not randomized, the same individual made all of the readings, and the readings were not all made on the same day. In consequence, the data were subject to systematic errors.

The readings are summarized in Table 3. Again, the readings show that paint films on tinned steel cannot be detected by backscattering of beta rays from strontium-90. With the strontium-90 instrument, the magnitude of the readings on paint films on less dense surfaces were approximately proportional to a function of the quantity of lead per unit area of surface. With the carbon-14 instrument, the magnitude of the readings on paint films on any surface was approximately proportional to the concentration of lead in the paint film. These relationships are shown in Figures 8 and 9.

The scaler was then set to give cumulative counts over 1-minute intervals. One-minute readings were made with both instruments on some of the reference coatings on wood. The readings are summarized and compared to the 1/10-minute readings in Tables 4 and 5.

As expected, the values for percentage of standard deviation for the 1-minute readings were smaller than those for the 1/10-minute readings. Values for the percentage of standard deviation for the strontium-90 instrument were smaller than the same values for the carbon-14 instrument. The relative magnitude of the standard deviation indicates that errors with the strontium-90 instrument are smaller than errors with the carbon-14 instrument; random errors with the 1-minute readings are smaller than for the 1/10-minute readings. Large, systematic errors, such as those caused by baseline drift, would upset that relationship.

Whether the readout is by ratemeter or scaler should not grossly alter the results. The scaler readings are theoretically more accurate. To the instrument operators, the backscatter gage-scaler combination seems to be much superior to the gage-ratemeter combination. The disadvantage of the scaler is that it adds $600 to the cost of the combination. The cost for the gage-ratemeter combination is approximately $800; the gage-scaler combination, $1,400.

X-Ray Fluorescence Analyzers

The Portable Lead Paint Analyzer, Model XK-3 (Figure 10), manufactured by Princeton Gamma Tech of Princeton, N.J., is an x-ray fluorescence analyzer employing a 10-millicurie cobalt-57 gamma radiation source. The instrument was developed for HUD under a contract monitored by NBS. It is a digital readout instrument giving the lead content of the paint film directly from 0.1 to 10.0 mg/sq cm. A reading of 10.0 mg/sq cm is obtained on all paint films with lead content equal to or greater than that amount.

The XK-3 was purchased and evaluated by CEL. Readings were made on the same reference coatings used for evaluating the other lead-paint analyzers. The results are summarized in Table 6; the variability of replicate readings on the same coatings is shown in Table 7.

The XK-3 proved to be specific for lead and could be used for coatings on any substrate. It was not necessary to apply a correction for substrate unless the substrate contained lead. The readings were consistent with the make-up of the reference coatings. The deviations from the stated lead content that occurred were most likely caused by errors in the stated values or by the presence of lead in the substrates.

The reference coatings, not as homogeneous as desired, were applied by a small brush and varied in thickness from site to site. Variability of individual readings appears to be less than 0.5 mg/sq cm.

The instrument was very easy to use. The readings appeared 15 seconds after the button was pressed and the instrument was immediately ready for a new reading. The cost of the instrument was $4,500.

Radiation Hazard of Paint Analyzers

The radiation safety officer for the Pacific Missile Test Center assessed the radiation hazards of the instruments used in this project for detecting lead in paint.

The operator was exposed to negligible radiation when the instruments were in the operating position with the probes directed away from the operator and into the painted surface. When the strontium-90 instrument was inverted with the source shutter open and the probe directed away from the painted surface, significant radiation levels were encountered. Even in the inverted position, no measurable radiation escaped from the carbon-14 instrument and negligible quantities escaped from the cobalt-57 instrument.

In the course of the technical evaluation of the instruments by CEL personnel, film badge dosimetry showed no radiation exposures. It can be concluded that, when they are properly used, none of the instruments evaluated at CEL present a radiation hazard to the user or to the general public.

As used in these instruments, possession of carbon-14 or strontium-90 requires a special license issued by the Nuclear Regulatory Commission (NRC). The cobalt-57 used in the XK-3 fluorescence analyzer is exempt from the requirements for a special NRC materials license. The instrument can be operated under a general license issued to the manufacturer. Use of the latter instrument could possibly result in cost saving to the Navy in that it would not be necessary for the activities using it to apply for a special NRC materials license.

OCCURRENCE OF LEAD-BASED PAINT IN RESIDENTIAL STRUCTURES

Non-Military Residences

Prior to 1940, paints with lead contents as high as 50% were widely used. The 1970 housing census (Ref 32) estimates that 1.8 million pre-1940 houses in the United States are delapidated. Essentially, all of these structures bear at least some paint with lead contents greater than 2 mg/sq cm, a level taken by convention to be an indication of significant lead contamination. Much of the paint is peeling or chipping and constitutes a potential health hazard.

A survey was conducted in Pittsburgh, Pa., to estimate the incidence of lead paint in housing. The survey was conducted by NBS and administered by the Allegheny County Health Department. NBS furnished the survey methodology, lead detection equipment, and training in the use of that equipment as well as monitored the survey and analyzed the results.

The Pittsburgh survey is the only major statistically designed housing survey for lead-paint hazards conducted to date. The survey covered a representative sampling of the entire Pittsburgh area, not just identifiable "lead belts." Four thousand dwellings were selected at random from the entire city.

There is no single index for representing the extent and degree of lead contamination. The only direct way for comparing dwellings is on a room by room basis and by the amount of lead on each surface type. Several readings were taken with a portable x-ray fluorescence lead-paint analyzer at various locations on different surface types. Table 8 summarizes the readings taken on the walls, windows, and doors.

Table 8 shows that lead contamination is greater on the doors and windows than on the walls. The mean reading for the walls is less than 2 mg/sq cm. In most rooms it is less than 1 mg/sq cm. This by no means indicates that there are no incidences of high lead concentration on the walls. The distribution of values is highly skewed, and many of the readings were greater than 15 mg/sq cm.

Table 9 illustrates this fact and shows the wide distribution of values for the lead content in the walls of a selected group of some 400 kitchens in the Pittsburgh area. More than half of the walls had less than 2 mg/sq cm of lead. However, the lead contents of 25 of them were greater than 15 mg/sq cm.

Selected Pre-1950 Navy Housing

At the invitation of NAVFAC, members of the NBS Lead Paint Poisoning Project inspected and evaluated the surfaces of selected pre-1950 Navy housing units at the Naval Station, Boston on 26 and 27 September 1972. Only four dwelling units were inspected. A series of readings were made at different locations in the buildings with a portable x-ray fluorescence lead-paint analyzer. The instrument was an older model of the x-ray fluorescence analyzer evaluated recently at CEL and described earlier in this report. Some of the readings are summarized in Table 10.

With the exception of kitchens and bathrooms, no other interior surfaces were coated with highly leaded paints. The exterior surfaces presented a more serious lead-poisoning hazard, both in terms of high levels of lead and the condition of the paint. At several locations, the exterior coatings were chipping and peeling, thus making them more accessible to children.

Navy Housing at San Diego

The Public Works Center, Naval Station, San Diego, Calif., formulated a practical program for implementing Navy Instruction 10365.2A (Ref 9). The program was planned to be carried out with existing funding and with the existing maintenance and inspection organization.

To initiate the program, task specifications and job descriptions were prepared. PWC painters were instructed to collect a specified number of paint samples from specified Navy quarters and to touch up the spots from which the paint samples were removed. Samples were collected from the exterior and interior walls and woodwork or trim of approximately 50 of the 5,000 apartments maintained by PWC, San Diego. A total of 250 samples were collected.

The samples were tested for lead with a CEL Weathered Paint Identification Kit (Ref 24) which was purchased from a specialty manufacturer.

It was possible to eliminate 150 of the 250 paint samples from further consideration because they were unquestionably negative by the sodium sulfide test. The other 100 samples were all sent out to be analyzed at a commercial testing laboratory. The 100 samples included all of those samples that were too dark to be tested by the sodium sulfide reagent and all of those for which the results were positive or questionable. Paint containing more than 0.5% lead was found only on wood; none was found on stucco, masonry, or plaster. The lead paint was found primarily on exterior woodwork and trim.

Funds budgeted for the San Diego survey were $9,500; only about half of the budgeted amount was expended. The cost was approximately $1 per housing unit.

At the completion of the survey, PWC San Diego sent the weathered paint samples to CEL for possible additional study. Each of the samples included a small piece of the substrate as well as of the paint film. Chips of paint were removed from a dozen or so samples for each substrate type and combined. The composite samples were ground in a small mortar and pestle and submitted to a commercial laboratory for analysis by x-ray fluorescence spectroscopy. The lead content of the paint chips from the interior plaster was 0.11%; from the interior wood, 0.97%; from the exterior stucco and concrete, 0.066%; and from the exterior wood, 2.2%. Values for the titanium content of the same four samples were 6.2%, 7.7%, 4.4%, and 11%, respectively. The x-ray spectra of all four samples also indicated the presence of minor quantities of calcium, zinc, and iron and traces of other elements.

A similar comparison was made relating the lead content of the paint and the date of construction of the housing. The comparison was limited to paint samples on exterior wood. The results of the comparison are given in Table 11.

When the samples were obtained for the previous experiment relating lead content to substrate composition, easily removable chips of paint, which tended to be the outer layers, were collected. For the comparison of lead content and date of construction, a special effort was made to obtain samples of undercoats and primers as well. Consequently, the lead content of the composite samples for the second experiment were markedly higher than for the first.

Table 11 shows that the lead content of the oldest housing was higher than that of the newest, but the correlation was far from perfect. Primers with a high lead content were widely used on exterior wood until quite recently, so lead-based paint is not restricted to older housing.

Table 11 gives only a partial picture of the relationship of quantity of lead and age of the housing. Paint thickness tends to be greater for older housing; therefore, the quantity of lead per unit area tends to be greater. Far more significant, however, is the fact that far more exterior wood is used on older housing than on new. The 1908 quarters were stately Victorian mansions with all-wood siding. The 1973 housing was nearly all stucco with only a few trim boards on the exterior.

The San Diego survey as well as the surveys at Boston and Pittsburgh clearly indicated that the most hazardous accumulations of lead-based paint are exterior wooden surfaces of residential structures. Epidemics of lead-based paint poisoning among children have usually occurred during the summer months. Efforts have been made to associate these outbreaks of lead poisoning to the action of vitamin D (the sunshine vitamin) in releasing stored lead from the bones. A more plausible explanation for the increase in lead poisoning during the summer might be that during the summer children play outdoors more, where they are exposed to greater quantities of lead-based paint and less adult supervision than indoors.

METHODS FOR ABATEMENT IN NAVY HOUSING

Procedures Required by LBPPPA

The amended LBPPPA requires that loose, cracked, peeling, or chipping paint shall be thoroughly washed, sanded, scraped, wire-brushed, or otherwise removed from applicable surfaces of residential buildings. The cleaned surfaces must then be covered with two coats of paint having a lead content no greater than 0.06% by weight.

Although not specifically stipulated in the LBPPPA or its amendments, chips of paint removed from residential structures must be collected and disposed of in a manner that will prevent their becoming accessible to children.

Lead-based paint on surfaces that are sound and tight does not need to be removed or covered before repainting unless the integrity of the paint cannot be maintained. In the latter case, the paint shall be completely removed or the surface covered with a suitable barrier material such as gypsum wall board, plywood, or plaster before any repainting is undertaken. Decision as to whether the integrity of the paint can be maintained is apparently left to the good judgment of the one doing the painting or inspecting.

Role of Paint Analysis

The wording of the original LBPPPA implied that there would be a legal requirement to determine the lead content of the paint on residences in which children might reside. Abatement procedures would follow if the lead content were greater than a certain established level. In the

LBPPPA as finally amended, there are no regulations requiring the analysis of old paint nor are there regulations requiring the removal of paint because its lead content exceeds a stipulated level.

When inspecting homes in which children with excessive levels of blood lead reside, public health officials have customarily considered that paint with a lead content in excess of 2 mg/sq cm was hazardous. The difficulty of establishing a universal limit at that level is that the majority of homes in the United States would require extensive abatement efforts and the cost would be prohibitive. Furthermore, even a level as strict as 2 mg/sq cm would meet with much objection by those advocating that essentially no lead be left remaining on residential structures.

It would seem appropriate for the Navy to specify lead content as one criterion establishing priority for abatement procedures. Paint films with a lead content greater than 10 mg/sq cm are certainly much more dangerous than films with a lead content of 2 mg/sq cm. A dozen or so thumbnail-sized chips of paint with lead contents greater than 10 mg/sq cm contain a potentially lethal dose of lead for a child. Repeated ingestion of lead paint with lead contents of 2 mg/sq cm are required for a lethal effect. Lead paint with lead contents of 40 mg/sq cm are found occasionally.

Requiring the removal of paint films having a lead content in excess of 10 mg/sq cm would probably involve only a small percentage of Navy housing. Yet, the requirement would eliminate the most dangerous accumulations of lead paint in Navy housing.

NBS Lead-Based Paint Abatement Program

NBS is providing technical assistance to HUD which, since passage of the LBPPPA, has conducted an extensive program to develop lead-paint hazard abatement methods. They have issued excellent technical reports (Ref 34,35) describing recommended procedures and a special report (Ref 36) comparing costs. The NBS reports are excellent references for maintenance engineering personnel.

As part of this on-going program, NBS carried out an experimental hazard abatement program (EHAP) involving the treatment of lead-paint hazards in 250 dwellings located in various major cities. Thirty homes in the Washington, D.C., area (Ref 37) were treated in the first phase of the program. Paint removal methods demonstrated included use of chemical solvents and use of a special heat gun. Replacement of windows, doors, and wood trim were also investigated, and test installations of various barrier materials were made. Unfortunately, all such procedures are very costly and must be restricted to the most essential.

Wooden Windows, Doors, and Exterior Siding

Making lead-based paint on wooden window frames, doors, and exterior siding inaccessible to children would greatly reduce any lead-paint poisoning hazard that might exist in Navy housing. The goal of eliminating these hazards might be better approached on an activity-wide or even Navy-wide basis than on a house-to-house or room-to-room approach.

CEL recently compared the relative costs of three methods for abating the hazard of lead paint on old wooden window frames (Ref 38). All the paint was removed from one window and frame, and new paint was applied. All painted surfaces of another window and frame were covered with contact vinyl. A third window and frame were replaced with a new one. The estimated costs ranged from $115 to $145 each for all three windows. Because the costs are so high, abatement would prudently only be considered in quarters where children are being housed.

An alternate solution would be to house families with small children in quarters other than those with old wooden-framed windows. The restriction would perhaps be of limited inconvenience because few such Navy housing units appear to remain. To reduce maintenance costs the wooden-framed windows are gradually being replaced by those with aluminum frames.

A similar restriction forbidding the quartering of families with small children in residences with all wood siding might also be of limited inconvenience. Because of ease of maintenance, stucco and masonry are steadily replacing wood siding in the construction of Navy housing. The best known remaining residences with wood siding are the large old Victorian mansions at many permanent Navy bases. These elegant old structures are usually reserved for senior officers and small children are not likely to be in residence.

Wooden doors are widely used, and complete Navywide abatement would be too costly. Abatement would of necessity be limited to doors with cracked and peeling paint.

An interesting approach to abatement for wooden doors was tried in the NBS program at Washington, D.C. Paint was stripped from the doors in portable dip tanks set up on the site.

An approach not tried on doors as yet is to cover them with a protective barrier. A material that appears to have promise for such use is a new wall and woodwork covering developed for HUD by Johns-Manville: an inexpensive fiberglass mat is applied to the surface with a special crosslinking adhesive. This covering is easy to apply, relatively inexpensive, and extremely tough and durable.

CONCLUDING SUMMARY

The wording of the original LBPPPA implied that there would be a legal requirement to determine the lead content of the paint on residences in which children lived. Abatement procedures would follow if the lead content exceeded a certain level that would be established. To implement the act, CEL undertook the development of field methods for the detection and removal of lead-based paint.

An inexpensive and easy to use "vest pocket" detector kit employing a sodium sulfide spot test reagent for lead was developed. The kit provides the best field method now available for determining whether a newly applied layer of paint complies with restrictions on lead content.

CEL also developed a beta-ray backscattering gage for detecting paint containing lead. The gage, which costs approximately $800, can be used for screening purposes but is not specific for lead and cannot be used on all surfaces. It could be calibrated for use on wood or plaster to detect paint film with a lead content in excess of 5 mg/sq cm.

An x-ray fluorescence lead-paint analyzer developed for HUD was purchased and evaluated at CEL. The instrument, which costs approximately $4,500, is specific for lead and can be used without calibration on any surface. It proved to be accurate and reliable for estimating the lead content of paint film at levels as low as 0.5 mg/sq cm and up to 10 mg/sq cm.

The highest concentrations of lead are usually found in the paint on wooden surfaces, especially on the exterior surfaces of doors, wood window frames, and wood siding. The paint or enamel on interior bathroom and kitchen walls and cabinets also frequently contains high concentrations of lead.

The amended LBPPPA requires that loose, cracked, or peeling paint on residential structures shall be thoroughly scraped, wire-brushed, or otherwise removed. The cleaned surface shall then be covered with two coats of paint having a lead content not greater than 0.06%. Lead-based paint that is sound and tight does not necessarily need to be removed or covered before repainting, unless the integrity of the paint cannot be maintained. In the latter case, the paint must be completely removed or covered with a suitable barrier material.

ACKNOWLEDGMENT

Professors J. W. Sayre and D. W. Wilson of the University of Rochester developed the aqueous sulphide reagent for lead detection.

Mr. W. L. Milne, Radiation Safety Officer at the Pacific Missile Test Center, evaluated the safety of the radiation instruments used in this investigation.

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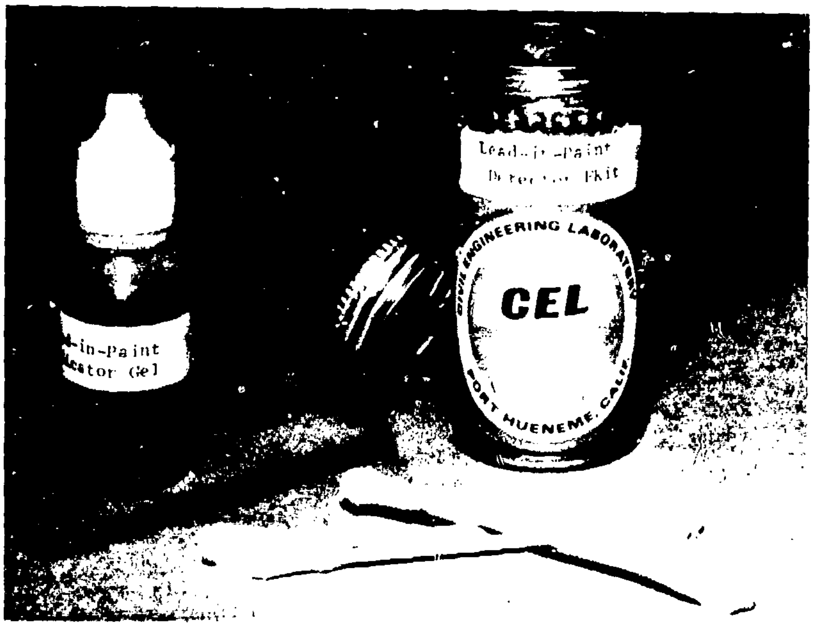

Figure 1. "Vest pocket" detector kit for lead in paint.

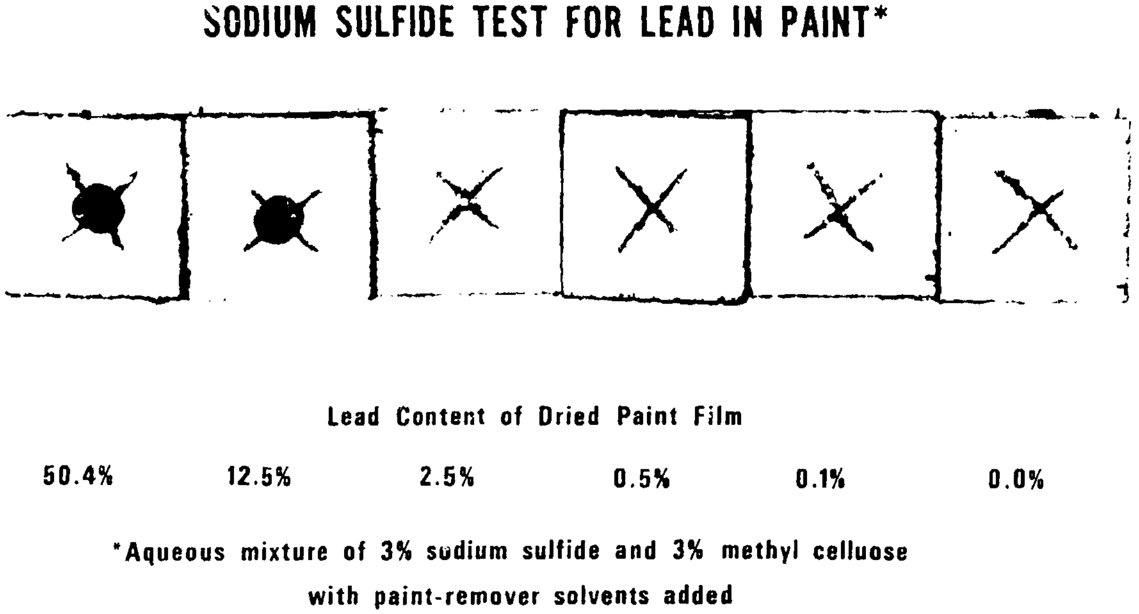

Figure 2. Spot tests on paint films containing various percentages of lead.

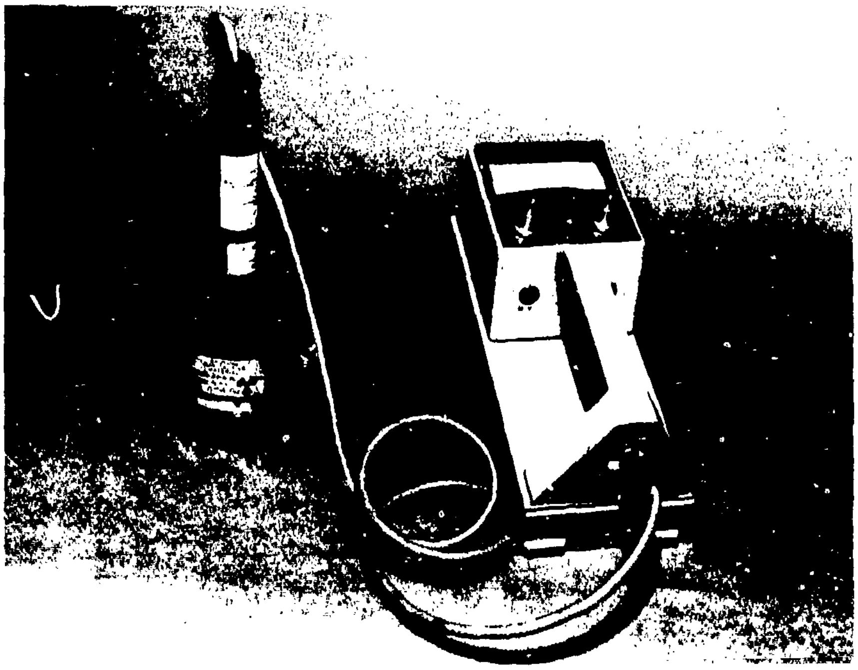

Figure 3. Paint thickness gage developed at CEL (prototype lead-in-paint gage).

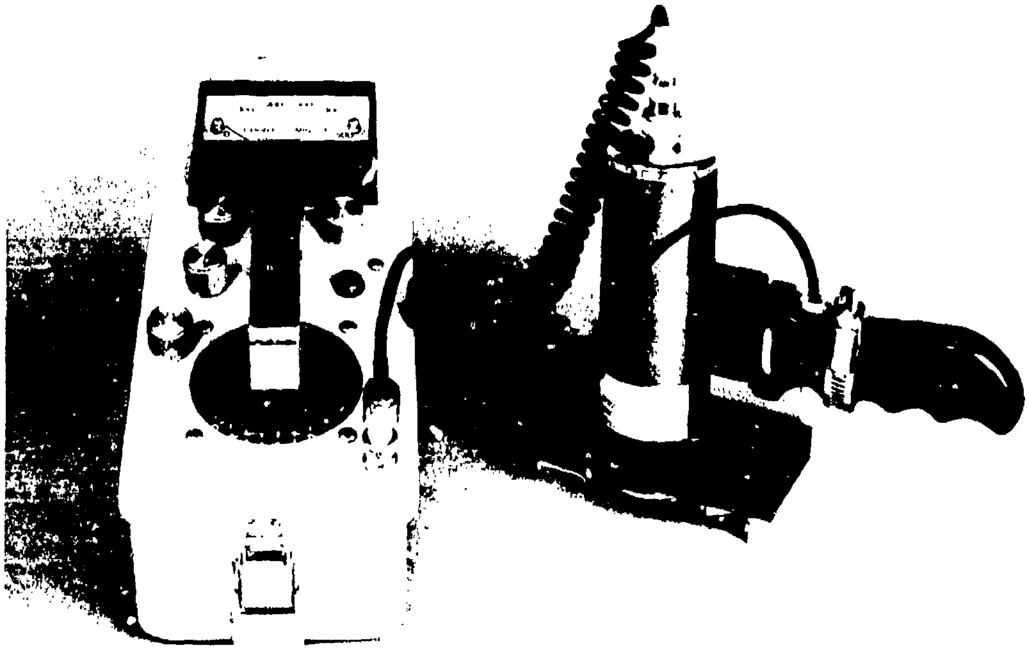

Figure 4. Commercial version of the CEL lead-in-paint gage.

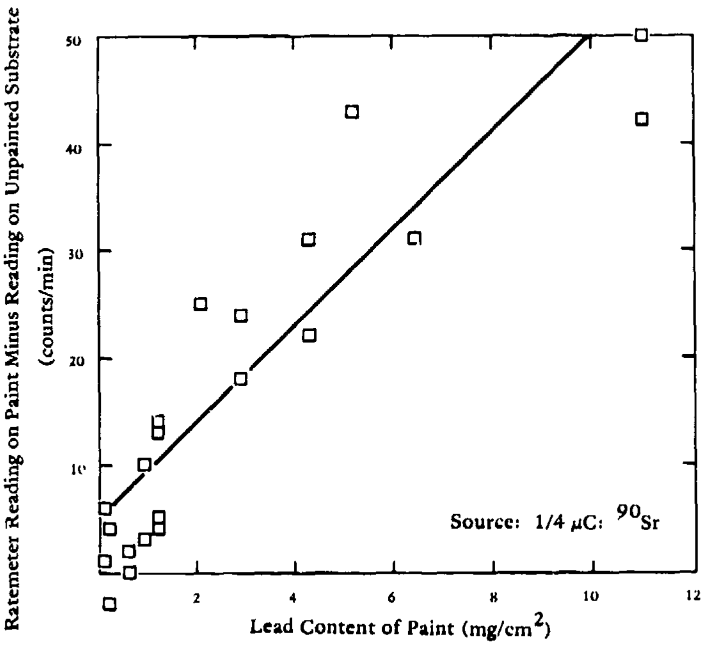

Figure 5. Plot of adjusted ratemeter readings from paint film versus quantity of lead per unit area.

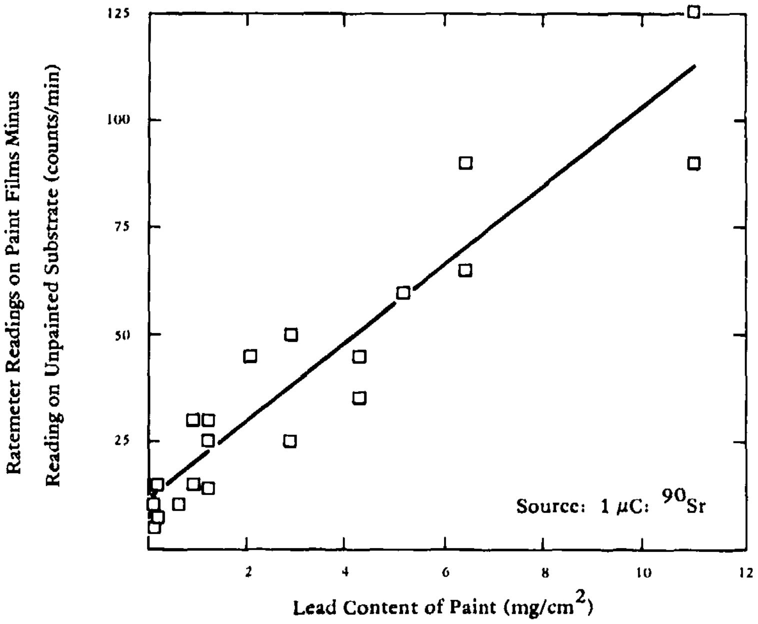

Figure 6. Plot of adjusted ratemeter readings from paint film versus lead content per unit area.

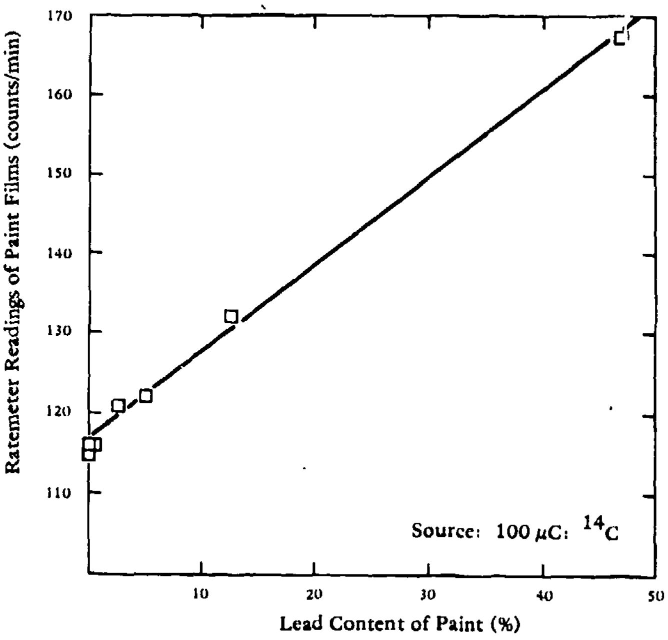

Figure 7 Plot of unadjusted scaler readings from paint film versus percent lead (strontium-90).

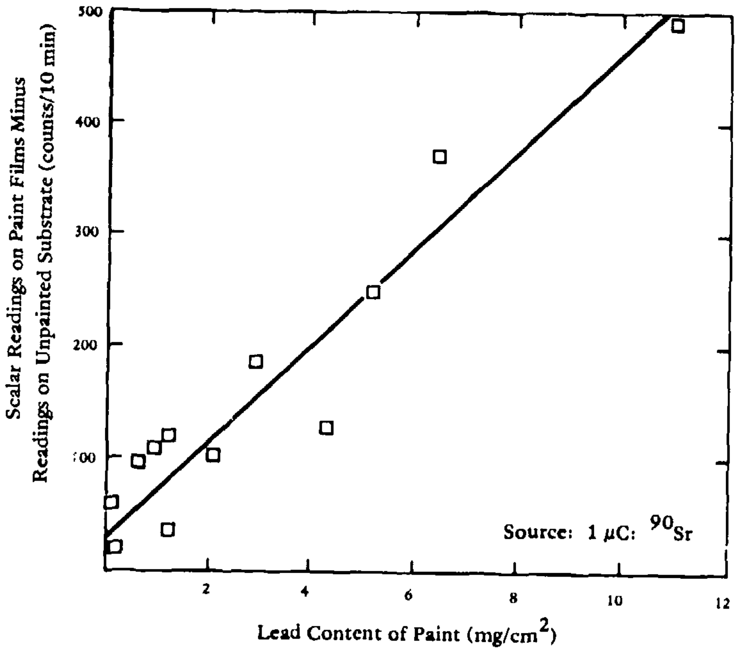

Figure 8. Plot of adjusted scaler readings from paint film versus lead content per unit area.

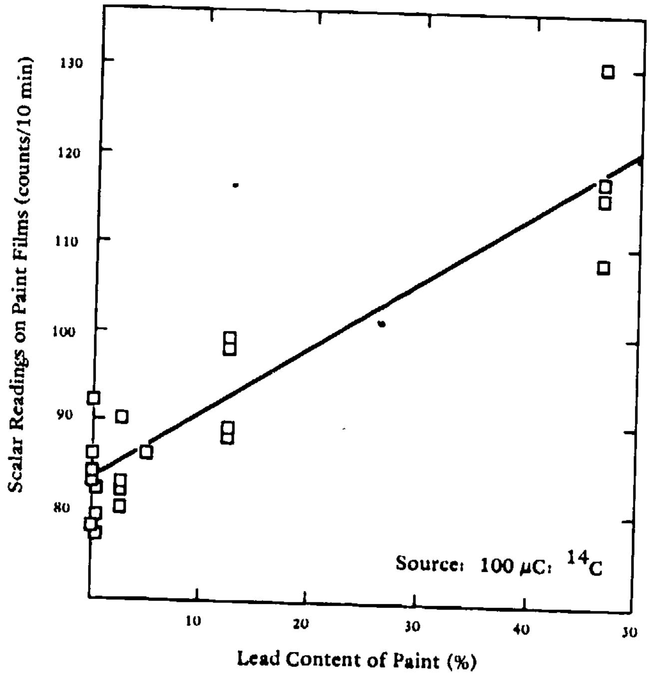

Figure 9. Plot of unadjusted scaler readings from paint film versus percent lead (carbon-14).

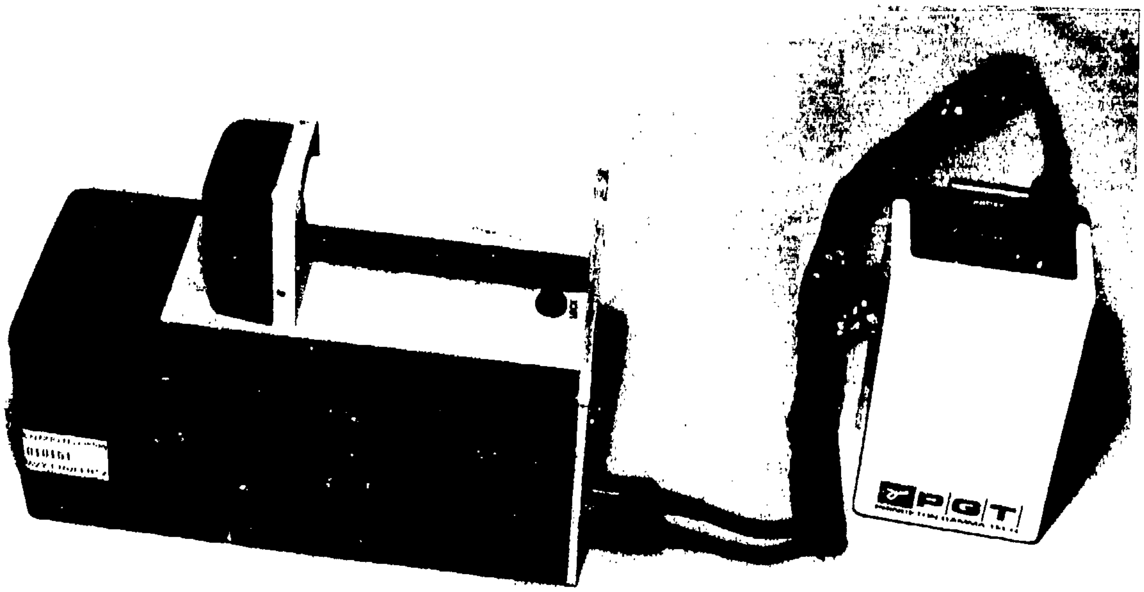

Figure 10. Portable x-ray fluorescence lead paint analyzer developed for HUD.

Table 1. Shelf Life of Sodium Sulfide Reagent for Detecting Lead in Paint

Temperature (°C)	Concentration of Residual Sodium Sulfide (Normality X10) After the Following Number of Days			
	0	57	134	268
10% Thickened Reagent				
35	12.39	10.60	8.90	4.74
20	12.39	10.88	9.86	7.28
5	12.39	11.72	11.4	10.34
3% Thickened Reagent				
35	3.58	2.51	0.69*	0.12*
20	3.58	2.91	1.39	0.54*
5	3.58	3.35	2.96	1.55
10% Unthickened Aqueous Reagent				
35	10.92	10.06	7.88	5.20
20	10.92	9.90	8.41	7.13
5	10.92	10.40	10.18	9.48
3% Unthickened Aqueous Reagent				
35	3.13	2.29	0.88*	0.38*
20	3.13	2.62	1.33	0.62*
5	3.13	2.95	2.42	1.52

*The reagent either failed to cause lead acetate paper to change color, or the color change was noticeably less pronounced than for the others.

Table 2. Ratemeter Readings Obtained by Two Different Observers Employing Three Different Backscattering Gages on Various Painted Surfaces

Substrate Surface	Coats of Paint	Lead Content of Paint		Readings[a] (counts/min) for --					
		%	mg/cm^2	1/4 μc Sr^{90} Scale x 100		1 μc Sr^{90} Scale x 100		100 μc C^{14} Scale x 10	
Steel (tin-coated)	0	--[b]	--	103	107	235	245	190	190
	1	2.5	0.3	90	108	235	210	115	118
	1	12.5	1.6	100	94	195	230	130	135
	1	46.7	11	105	102	240	245	160	162
Wallboard (paper-covered gypsum)	0	--	--	49	48	125	105	95	100
	1	2.5	0.6	51	48	135	125	120	125
	1	12.5	2.9	57	62	160	155	130	135
	1	46.7	11	91	98	215	230	170	160
Hydrostone (plaster-of-paris)	0	--	--	56	55	115	128	110	115
	1	2.5	0.2	53	59	130	135	115	122
	1	12.5	1.2	61	59	140	142	135	135
	1	46.7	4.3	57	77	150	173	165	170
Wood	0	--	--	22	27	90	95	90	90
	1	2.5	0.1	28	28	100	100	120	130
	1	12.5	0.9	32	30	105	125	130	128
	1	46.7	6.4	53	58	155	185	170	175
Wood	2	5	1.2	43	43	110	110	120	120
	4	5	2.1	54	55	125	125	125	115
	8	5	5.2	72	73	140	140	120	125
Wood	2	0	0	39	40	105	105	110	120
	4	0	0	46	48	110	110	115	110
	8	0	0	54	54	125	120	125	120
Lead	0	--	--	181	182	440	450	243	240

[a] μc Sr^{90} = microcurie strontium-90; μc C^{14} = microcurie carbon-14.

[b] -- indicates no paint used.

Table 3. Scaler Readings of Backscattering From Various Painted Surfaces With Two Different Gages

Substrate Surface	Coats of Paint	Lead Content of Paint		Readings[a] (counts/1/10 min) for --			
				1 μc Sr^{90}		100 μc C^{14}	
		%	mg/cm^2	Average	Standard Deviation	Average	Standard Deviation
Steel (tin-coated)	0	--[b]	--	1,268	26	139	11
	1	2.5	0.3	1,155	12	82	7
	1	12.5	1.6	1,201	16	89	6
	1	46.7	11	1,289	16	108	12
Wallboard (paper-covered gypsum)	0	--	--	702	20	63	8
	1	2.5	0.6	796	17	83	12
	1	12.5	2.9	888	21	98	9
	1	46.7	11	1,192	12	130	16
Hydrostone (plaster-of-paris)	0	--	--	815	19	80	6
	1	2.5	0.2	833	22	80	9
	1	12.5	1.2	870	14	88	11
	1	46.7	4.3	1,002	19	115	8
Wood	0	--	--	475	15	61	5
	1	2.5	0.1	534	17	90	4
	1	12.5	0.9	583	31	94	5
	1	46.7	6.4	845	27	117	8
Wood	2	5	1.2	958	22	84	17
	4	5	2.1	941	11	84	15
	8	5	5.2	1,089	32	84	11
Wood	2	0	0	986	10	76	18
	4	0	0	925	50	75	13
	8	0	0	1,050	34	80	19
Lead	0	--	--		0	161	

[a] μc Sr^{90} = microcurie strontium-90; μc C^{14} = microcurie carbon-14.

[b] -- indicates no paint used.

Table 4. Comparison of 1/10-Minute and 1-Minute Readings of Painted Wooden Panels With Beta-Ray Backscattering Gage Having a 1 Microcurie Strontium-90 Source

Coats of Paint	Lead Content of Paint		1/10-Minute Readings			1-Minute Readings		
	%	mg/cm^2	Average of 5 Counts	Standard Deviation	Standard Deviation (%)	Average of 3 Counts	Standard Deviation	Standard Deviation (%)
0	--[a]	--	475	15	3.2	6,468	110	1.7
1	0.0	0	520	22	4.2	7,606	173	2.3
1	0.1	<0.1	533	18	3.4	7,988	43	0.5
1	0.5	<0.1	519	19	3.7	7,693	136	1.8
1	2.5	0.1	534	17	3.2	7,844	101	1.3
1	12.5	0.9	583	31	5.3	8,529	58	0.7
1	46.7	4.4	845	27	3.2	13,708	21	0.2
1	5.0	0.7	897	15	1.7	9,116	65	0.7
2	5.0	1.2	958	22	2.3	9,840	67	0.7
4	5.0	2.1	941	11	1.2	11,059	153	1.4
6	5.0	3.9	1,079	17	1.6	12,464	52	0.4
8	5.0	5.2	1,089	32	2.9	13,065	143	1.1
1	>0.5	<0.1	862	26	3.0	7,760	44	0.6
2	>0.5	<0.1	981	10	1.0	8,622	74	0.9

(continued)

Table 4. Continued

Coats of Paint	Lead Content of Paint		1/10-Minute Readings			1-Minute Readings		
	%	mg/cm^2	Average of 5 Counts	Standard Deviation	Standard Deviation (%)	Average of 3 Counts	Standard Deviation	Standard Deviation (%)
4	>0.5	<0.2	925	50	5.4	9,283	70	0.8
6	<0.5	<0.4	887	21	2.4	10,258	95	0.9
8	>0.5	<0.5	1,050	34	3.2	10,848	96	0.9
Average					3.0			0.9

[a]-- indicates no paint used.

Table 5. Comparison of 1/10-Minute and 1-Minute Readings of Painted Wooden Panels With A Beta-Ray Backscattering Gage Having A 100 μc C^{14} Source

Coats of Paint	Lead Content of Paint		1/10-Minute Readings			1-Minute Readings		
	%	mg/cm^2	Average of 4 Counts	Standard Deviation	Standard Deviation (%)	Average of 3 Counts	Standard Deviation	Standard Deviation (%)
0	--[a]	--	61	5	8	665	10	2
1	0.0	0	86	10	12	890	27	3
1	0.1	<0.1	84	13	15	888	14	2
1	0.5	<0.1	79	11	14	886	7	1
1	2.5	0.1	90	4	4	919	46	5
1	12.5	0.9	94	5	5	960	43	4
1	46.7	6.4	117	8	9	1,328	22	2
1	5.0	0.7	78	4	5	868	13	1
2	5.0	1.2	84	1	1	919	46	5
4	5.0	2.1	77	7	9	938	85	9
6	5.0	3.9	84	8	10	942	48	5
8	5.0	5.2	84	10	12	978	10	1
1	<0.5	<0.1	78	13	17	884	41	5
2	<0.5	<0.1	76	4	5	861	29	3

(continued)

Table 5. Continued

Coats of Paint	Lead Content of Paint		1/10-Minute Readings			1-Minute Readings		
	%	mg/cm^2	Average of 4 Counts	Standard Deviation	Standard Deviation (%)	Average of 3 Counts	Standard Deviation	Standard Deviation (%)
4	<0.5	<0.2	76	8	11	865	23	3
6	<0.5	<0.4	75	9	12	870	44	5
8	<0.5	<0.5	80	6	7	879	47	5
Average					9.2			3.6

[a]-- indicates no paint used.

Table 6. Performance of Portable X-Ray Fluorescent Lead-Paint Analyzer Developed for HUD

Substrate	Coats of Paint	Lead Content of Paint		Average of Readings (mg/cm^2)	Standard Deviation
		%	mg/cm^2		
Tinned Steel	0	--[a]	--	0.8	0.3
	1	2.5	0.3	1.1	0.2
	1	12.5	1.6	2.9	0.2
	1	46.7	11	>10	--[b]
Wallboard (gypsum)	0	--	--	0.5	0.2
	1	2.5	0.6	1.1	0.2
	1	12.5	2.9	4.0	0.4
	1	46.7	11	>10	--[b]
Hydrostone (plaster-of-paris)	0	--	--	0.2	0.2
	1	2.5	0.2	0.5	0.3
	1	12.5	1.2	1.4	0.1
	1	46.7	4.3	4.2	0.2
Wood	0	--	--	0	0.1
	1	2.5	0.1	0.1	0.2
	1	12.5	0.9	1.4	0.2
	1	46.7	6.4	6.6	0.4
	1	5	0.7	0.6	0.2
	2	5	1.2	1.1	0.3
	4	5	2.1	2.3	0.2
	6	5	3.9	4.3	0.4
	8	5	5.2	5.7	0.3
	8	<0.5	<0.5	0.1	0.1
Lead	0	--	--	>10	--[b]

[a] -- indicates no paint used.

[b] Gage reads only up to 10.0.

Table 7. Variability of Two Sets of Five Replicate Readings Made With HUD-Developed Portable Lead Paint Analyzer on Enameled Wooden Panels

Coats of Enamel	Lead Content (mg/cm^2)	Values of Five Replicate Readings of Lead Content (mg/cm^2)					Average (mg/cm^2)	Standard Deviation
		1	2	3	4	5		
1	0.7	0.4	0.9	0.8	0.5	0.7	0.7	0.2
1	0.7	0.7	0.2	0.5	0.3	0.8	0.5	0.2
2	1.2	1.1	1.4	0.5	1.4	0.9	1.1	0.4
2	1.2	1.3	1.1	1.1	1.5	0.9	1.2	0.2
4	2.1	2.2	2.2	2.3	2.2	2.2	2.2	0.1
4	2.1	2.5	2.7	2.7	2.[illegible]	1.8	2.4	0.4
6	3.9	4.8	5.0	4.5	5.0	3.5	4.6	0.6
6	3.9	4.0	3.9	4.3	4.4	4.1	4.1	0.2
8	5.2	5.8	5.1	5.9	5.8	5.3	5.6	0.4
8	5.2	6.0	6.3	5.8	5.4	6.0	5.9	0.3

Table 8. Comparison of The Lead Content of Paint on The Walls, Doors, and Windows of Residences in The Pittsburgh Area[a]

Room	Walls		Windows		Doors	
	Mean Lead Content (mg/cm^2)	Standard Deviation	Mean Lead Content (mg/cm^2)	Standard Deviation	Mean Lead Content (mg/cm^2)	Standard Deviation
Living	0.6	2.6	2.9	4.5	2.6	4.2
Dining	0.8	3.2	2.5	3.9	3.6	4.7
Family	0.8	3.1	2.6	4.6	2.4	3.9
Kitchen	1.8	4.5	2.9	4.3	3.6	4.7
Bathroom	2.0	4.5	3.7	5.7	3.3	4.9
Bedroom	0.5	2.3	3.0	4.5	2.9	4.2
Stairway	0.9	3.1	2.5	4.0	2.1	3.5
Hall	0.8	2.8	3.4	3.5	2.3	3.6
Basement	0.9	2.9	3.0	4.1	3.2	3.8

[a] Data from Reference 33.

Table 9. Frequency Distribution of Readings on Lead-Paint Analyzer of Paint on The Walls of Selected Kitchens in Pittsburgh Area[a]

Range of Values (mg/cm^2)	Number of Readings
0 through 0.9	160
1 through 1.9	75
2 through 2.9	25
3 through 3.9	20
4 through 4.9	20
5 through 5.9	10
6 through 6.9	10
7 through 7.9	5
8 through 8.9	0
9 through 9.9	10
10 through 10.9	5
11 through 11.9	5
12 through 12.9	5
13 through 13.9	10
14 through 14.9	5
15 through 15.9	10
16 and greater	25

[a] Data from Reference 33.

Table 10. Lead Content of Paint on Surfaces of Selected Pre-1950 Navy Housing in The Boston Area

Description of Surface	Lead Content (mg/cm^2)
Exterior wood garage door	7.0
Interior living room plaster wall	0.3
Interior bedroom metal window sill	-0.2
Interior bedroom gypsum wallboard	0.1
Interior kitchen gypsum wallboard	3.4
Interior bathroom gypsum wallboard	3.8
Interior bed, dining, living rooms gypsum board	0.0
Exterior wood faciaboard 18 inches above ground	6.3
Exterior walls, fiberboard sheathing	32.0
Exterior metal downspout	8.0

Table 11. Relationship of Date of Construction and Lead Content of Paint on Wooden Exterior Surfaces of Navy Housing in the San Diego Area

Date of Construction	Lead Content of Composite Paint Sample (%)
1904	17.0
1941	9.6
1953	2.3
1954	15.0
1960	2.6
1965	5.4
1965	7.1
1973	2.6

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NAVFACENGCOM CONTRACT AROICC, Point Mugu CA; AROICC, Quantico, VA; Code 05, TRIDENT, Bremerton WA; Code 09E, TRIDENT, Bremerton WA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC (Knowlton), Kaneohe, HI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC (Ervin) Puget Sound Naval Shipyard, Bremerton, WA; ROICC (LCDR J.G. Leech), Subic Bay, R.P.; ROICC AF Guam; ROICC LANT DIV., Norfolk VA; ROICC Off Point Mugu, CA; ROICC, Diego Garcia Island; ROICC, Keflavik, Iceland; ROICC, Pacific, San Bruno CA
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NAVOCEANSYSCEN Code 52 (H. Talkington) San Diego CA; Code 5224 (R.Jones) San Diego CA; Code 6565 (Tech. Lib.), San Diego CA; Code 6700, San Diego, CA; Code 7511 (PWO) San Diego, CA; Research Lib., San Diego CA; SCE (Code 6600), San Diego CA
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NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPGSCOL E. Thornton, Monterey CA; LCDR K.C. Kelley Monterey CA
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NAVSEC Code 6034 (Library), Washington DC
NAVSECGRUACT Facil. Off., Galeta Is. Canal Zone; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSHIPREPFAC Library, Guam; SCE Subic Bay
NAVSHIPYD; CO Marine Barracks, Norfolk, Portsmouth VA; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, (Woodroff) Norfolk, Portsmouth, VA; Code 400, Puget Sound; Code 400.03 Long Beach, CA; Code 404 (LT J. Riccio), Norfolk, Portsmouth VA; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 440.4, Charleston SC; Code 450, Charleston SC; Code 453 (Util. Supr), Vallejo CA; L.D. Vivian; Library, Portsmouth NH; PWD (Code 400), Philadelphia PA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI; Tech Library, Vallejo, CA
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NCBU 411 OIC, Norfolk VA
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NCSO BAHRAIN Security Offr, Bahrain
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