

Lead Levels in the Household Environment of Children in Three High-Risk Communities in California¹

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To assess environmental lead contamination in the household environment of children in high-risk areas of California, three urban locations were surveyed by the California Department of Health Services. Plant, soil, and dust lead levels were measured and a questionnaire was administered. This survey estimates that 3 million homes in California (27%) may have exterior paint lead levels ≥ 5000 ppm, and 1.3 million homes (12%) may have interior paint lead levels ≥ 5000 ppm. The highest concentrations of lead in paint were found on exterior surfaces and, for homes built between 1920 and 1959, on trim. Age of housing was the best predictor of lead in soil and dust; homes built before 1920 were 10 times more likely to have soil lead levels ≥ 500 ppm compared to post-1950 homes. Most of the variability in dust lead levels could not be explained by factors measured in this survey. Sources of lead in the home were more highly correlated with lead dust concentration levels than they were with lead dust loading levels. Households with members reporting a lead job were twice as likely to have high dust lead levels compared to households with no one reporting a lead job. The significant differences in dust lead concentration levels between communities were not reflected in differences in dust lead loading levels. Measuring dust lead loading levels does not appear to be a meaningful sampling method for risk assessment in the context of prioritizing abatement. © 1995 Academic Press, Inc.

INTRODUCTION

Lead is one of the most widely dispersed toxic substances of this century (Shy, 1990). Sources of lead

in the household environment of children include lead paint, automotive and industrial lead emissions, and lead in food and water. Lead from paint and airborne emissions deposits on soil and in dust; lead also deposits in house dust as a result of being tracked in on shoes, brought home from the workplace, produced as a result of home renovation activities, and generated by hobbies that involve lead (U.S. Centers for Disease Control, 1991; Baker *et al.*, 1977). Once deposited in the environment lead does not break down. Regulations enacted during the 1970s reduced the amount of new lead being introduced into the home environment (U.S. Environmental Protection Agency, 1986); however, no systematic efforts have been made in California to reduce or eliminate environmental lead already present in homes from the previous century of use. Moreover, scientific evidence continues to link serious (and potentially irreversible) health effects with exposure to lead at levels previously considered low (Needleman *et al.*, 1990; Needleman and Gatsonis, 1990; McMichael *et al.*, 1988; Bellinger *et al.*, 1987).

In response to the concern that levels of lead of public health significance might be present in the household environment of young children in California, between 1987 and 1991, the California Department of Health Services (CDHS)² undertook population-based surveys at selected households in three communities considered to be at high risk for childhood lead poisoning. From National Health and Nu-

¹ This work was conducted entirely by the California Department of Health Services and does not represent the official or unofficial policies of the U.S. Environmental Protection Agency.

² Abbreviations used: CDHS, California Department of Health Services; HUD, U.S. Department of Housing and Urban Development.

trition Examination Survey (NHANES) data, it was expected that children at most risk would be between the ages of 1 and 6 years and would live in densely populated communities (National Center for Health Statistics, 1982). It was also presumed that exposure to lead was most likely in children living in areas predominated by older housing and industrial and/or automotive emissions and with cultural and/or ethnic characteristics which increase their risk (such as the use of folk medicines). At each household surveyed, environmental samples for lead were collected, a questionnaire exploring risk factors for lead poisoning was administered, and blood samples were obtained.

This paper describes the levels of lead measured in paint, soil, and housedust in these three communities considered to be at high risk for childhood lead poisoning. A second purpose is to evaluate how well environmental lead levels are predicted by age of housing. Because soil and dust are considered to be important pathways of lead exposure, a third purpose is to explore the interrelationships between dust and soil lead levels measured and other factors measured by this study which are expected to influence dust and/or soil lead levels (age of housing, paint lead levels, paint deterioration, renovation activities, and jobs and hobbies involving lead). The results of the blood lead sampling, questionnaire data, and the assessment of exposures for individual children living in high-risk communities will be presented elsewhere (Goldman *et al.*, 1995).

MATERIALS AND METHODS

Selection of High-Risk Communities and Households

In 1986, a law was passed in California that mandated that CDHS survey high-risk communities in the northern, central, and southern parts of the state for childhood lead poisoning (California Health and Safety Code). CDHS chose Alameda, Sacramento, and Los Angeles counties as the general areas from which specific communities would be selected. Within each of the three counties, communities at high risk for childhood lead poisoning were selected based on a high prevalence of factors specified in the statute, including many children between the ages of 1 and 6 years, older housing, and populations having cultural and/or ethnic risk factors. The proportion of children ages 1 to 6 and the age of the housing for census tracts within each county were ascertained using 1980 census data. Census tracts having both a high proportion of older housing and young children were further evaluated for risk through discussions with local health agen-

cies and by first-hand observation. In the Oakland and Sacramento communities, any households in the selected census tracts having a child between 1 and 6 years of age living in the household were eligible. In the Los Angeles survey area, a random sample of blocks in each of two selected census tracts was selected, and any households on the selected blocks having a child of age 1 to 6 in residence were eligible to participate. A complete description of the sample selection and response rates will be presented elsewhere (Goldman *et al.*, 1995).

Paint Sampling

Paint samples were collected at each household after technicians made a visual inspection of all painted surfaces. Technicians rated separately the interior and exterior paint condition on a scale of 1 (excellent—no flaking, peeling, or chipping paint) to 5 (very deteriorated paint on several surfaces). Different technicians rated the paint condition in each of the three areas. Up to three interior and three exterior paint samples from different areas of peeling and/or chipping paint were collected. Indoor trim (including windows, woodwork, doorways, stairs, etc.) was sampled in preference to walls. Outdoor trim and porches were sampled in preference to siding. In the Sacramento area only, paint samples were collected from intact surfaces if there was no peeling or chipping paint available. Paint chips were removed following CDHS's standard practice of using a clean penknife and were placed in a plastic Whirl-pak bag.

Soil Sampling

All soil samples were obtained from the top inch or less of soil using a clean trowel. Any visible paint chips from the soil were removed before collecting and/or analyzing the sample. Up to five samples were collected in Oakland and Los Angeles and up to three samples were collected in Sacramento at each household. In all three survey areas, soil samples were obtained from the front, rear, and side yards. In Oakland and Los Angeles, soil samples were also collected next to additional structures (such as a garage) and under the rain drain. Each soil sample was composited from four subsample points except for the rain-drain sample, which was collected from one scoop of soil directly under the rain-drain spout. Samples from the four composite points were placed in the same plastic Whirl-pak bag.

Dust Sampling

Dust samples in the Los Angeles and Sacramento survey areas were collected with a three-horsepower Mighty-Mite vacuum (Model 3130) onto a Teflon-

coated, 102-mm filter (T60A20; 98% efficient at 0.3 μm ; Pallflex Products Corp., Putnam, CN). In Los Angeles, the first area where dust samples were collected, an area 1m^2 in the center of the room, was vacuumed for 4 min. To increase the quantity of dust collected, the area vacuumed in the Sacramento survey was doubled. Vacuuming time for the 2m^2 area was also 4 min. Samples were collected from both noncarpeted and carpeted floors. Where both carpeted and noncarpeted floors were available in a home, the dust sample was collected from a noncarpeted floor. After vacuuming, the preweighed filter was carefully removed from the filter holder and placed in a larger petri dish. The filter holder was then lightly sprayed with 50% ethanol in distilled water and wiped with two preweighed $2'' \times 2''$ gauze pads. Next, the gauze pads were placed in the petri dish along with the filter and submitted to the laboratory. After temperature and humidity equilibration ($T = 25^\circ\text{C}$, $\text{RH} = 50\%$), the samples were reweighed followed by analysis for lead. The laboratory reported surface dust lead loading ($\mu\text{g lead}/\text{m}^2$) and lead dust concentration ($\mu\text{g lead}/\text{g dust}$ or ppm). Dust lead loading and dust lead concentration are different measures of environmental lead levels: dust lead concentration (ppm) is a measure of how much lead is in a given quantity of dust, while dust lead loading ($\mu\text{g}/\text{m}^2$) is a function of both the concentration of lead in dust and the quantity of dust on the surface sampled and, as such, will be influenced by housekeeping before sample collection.

Analytical Methods and Quality Control

Paint, soil, and dust lead levels were analyzed by flame atomic absorption spectrophotometry (AAS) at a wavelength of 283.3 nm using a Perkin-Elmer Model 5000 instrument.

Paint samples were dry ashed and digested in hot concentrated nitric acid and the acid extract was analyzed as previously described (Air Industrial Hygiene Laboratory, 1986). With each batch of 10 to 15 samples, the recovery of lead was measured in a paint standard (National Institutes of Standards and Technology Standard Reference Material (SRM) 1579) which has a lead concentration of 11.87%. The average recovery of lead was 97%. Recoveries in 29 of 30 separate measurements fell within the acceptable 90 to 110% range for calibration verification using SRMs as specified in the reporting requirements for metals by atomic absorption in the USEPA Contract Laboratory Program. The recovery in the 30th measurement was 88%. Duplicate samples of SRM 1579 were also analyzed with each batch of samples. The relative percentage difference

(relative standard deviation \times square root of 2) in lead content among these duplicates averaged 5% (range: 0–10%). This degree of precision is well within the relative percentage difference of less than 20% for duplicates required for reporting under the USEPA Contract Laboratory Program.

Soil samples were air dried (very moist samples were oven dried), ground, sieved, and digested with concentrated nitric acid. The acid extracts were analyzed for lead by flame atomic absorption as previously described (Air Industrial Hygiene Laboratory, 1988). The method gave an average lead recovery of 94% in a river sediment standard (SRM 2704) containing 155 ppm lead. Seven of eight recoveries were within the 90 to 110% range acceptable to the USEPA Contract Laboratory Program; the recovery in the eighth sample was 84%. Recoveries were also determined in selected samples from the community surveys by spiking soils with aqueous lead standards; the recoveries in the five matrix spikes ranged from 93 to 114%, indicating that matrix interferences were not large. The matrix spike recoveries were all within the acceptable range of 75 to 125% for recovery of metals in matrix spikes required for reporting in the USEPA Contract Laboratory Program. Quality control on routine analysis of soil samples was maintained by analyzing two soil controls with every batch of 8 to 12 samples. The two soil controls were prepared by blending community soils, and their target values (2076 ppm for a "high" and 246 ppm for a "low" lead control) were established by analyzing 20 samples of each. The lead recoveries in 27 measurements of the routine control samples ranged from 89 to 108% of the target values. All of these results met the USEPA Contract Laboratory Program reporting requirement that recoveries in routine controls fall between 80 and 120%.

Samples of dust were collected on filters and gauze pads as described above. The samples were digested with hot, concentrated nitric acid, and the extracts were filtered, diluted to a known volume, and analyzed by flame AAS as described elsewhere (Guirguis, 1988). The method gave lead recoveries ranging from 91 to 108% in 8 of 9 samples of SRM 2704 (above) analyzed. The recovery in the ninth sample was 84%. As described above, the USEPA Contract Laboratory Program requires that recoveries in SRMs used for calibration verification should be within the range of 90 to 110%. Routine soil control samples (see above) were run in parallel with each batch of 8 to 12 dust samples. Recoveries in 24 routine control determinations ranged from 92 to 109% of the target values. Thus, all 24 recoveries met the

USEPA Contract Laboratory Program reporting requirement for routine controls described above. The intralaboratory precision of dust sample collection and analysis, as measured by the relative percentage difference, averaged 17% among four sets of duplicates; however, the relative percentage differences between two of the four sets of duplicates exceeded the 20% precision-reporting requirement for reporting in the USEPA Contract Laboratory Program (they were 21 and 38%). The relative imprecision among the dust sample duplicates probably reflects variability in sampling rather than in analysis. It is generally recognized that dust sampling is difficult to standardize.

Questionnaire

Information regarding paint renovation activity, jobs, and hobbies involving lead and housing subsidization was obtained by interview. Participants were asked if in the past 12 months there were any changes made to the paint in the home (sanding, scraping, burning, etc.). Participants were also asked if any household resident was employed in any one of 11 jobs determined *a priori* to have a potential for lead exposure: storage battery manufacture; firing range; radiator repair; sand, cut, or weld metal; solder; sandblasting; remove paint or painting; use of inks, dyes, or glazes; cut cable; smelting; make paints, inks, or dyes; and casting lead, bronze, or brass. A "yes" response to any of the listed jobs was categorized as a house with a resident employed in a lead job; otherwise, the house was categorized as having no one with a lead job. Participation in lead hobbies was ascertained in the same way as jobs. Hobbies asked about were pottery; stained glass; soldering; firing range; make lead fishing weights or bullets; car work; paint furniture or parts of house; model cars, boats, or planes; art; and electronics. Information regarding housing subsidization was obtained by asking if the home was owner occupied, rented, or if the participant received any publicly funded subsidization such as public housing or Section 8.

Statistical Methods

To characterize environmental lead levels at each household for statistical purposes, the highest single paint lead level collected from the interior of the home was used for analysis of the indoor paint lead levels. The maximum outdoor paint lead level at each house was also used for statistical analysis. An average household soil lead level for each house tested was computed by taking the geometric mean of all the soil samples collected at the house. Environmental lead levels in soil, paint, and dust were

approximately log-normally distributed; therefore, these results were log-transformed for analysis (natural logarithm). Geometric means, medians, ranges, and geometric standard deviations for indoor paint, outdoor paint, soil, and dust variables were computed. Paired *t* tests were used to evaluate differences between interior and exterior paint lead levels and paint lead levels on trim compared to walls. Analysis of variance was used to compare indoor paint lead levels by room sampled.

To explore the relationship between environmental lead levels measured and age of housing, the age of each house surveyed was ascertained by merging the participants' addressees with the records of the county assessor. All variables were then categorized and differences were assessed by the χ^2 test. Spearman correlation coefficients between age of housing and environmental lead levels were also calculated.

In addition to age of housing, other variables expected to influence soil lead levels were outdoor paint lead levels, reported paint changes, and condition of exterior paint; other variables expected to influence dust lead levels were soil lead levels, indoor and outdoor paint lead levels, reported paint changes, condition of interior and exterior paint, lead jobs, and hobbies. The extent and statistical significance of these relationships were explored using the χ^2 test and by calculating Spearman correlation coefficients for all continuous variables. *t* tests were used to compare mean dust lead levels in homes with and without reported paint changes, lead jobs, and lead hobbies.

To assess the independent statistical relationship of these variables on soil and dust lead levels multivariate logistic and linear regression analysis was undertaken. All continuous variables were categorized into a high and low group for the logistic regression model. The groups were dichotomized based upon levels previously reported in the literature or, when not available, the upper quartile of their distribution. Continuous variables were used for the multiple linear regression modeling. All independent variables, with the exception of indoor and outdoor paint ratings, were retained in the model whether or not they were statistically significant in a two-tailed test of the hypothesis that their regression coefficient was zero. Indoor and outdoor paint condition ratings were not included in the final model because different interviewers rated the homes in different areas and the subjective nature of this rating precluded the ability to combine the three areas for this variable. Odds ratios, 95% confidence intervals, and the proportion of the variance explained by the model were calculated. All potential interactions were assessed and no effect modifi-

cation was observed. Regression assumptions of independence, linearity, normality, and constant variance were assessed for all models.

RESULTS

Houses Surveyed

Three hundred fifty-eight (358) households were surveyed in the Oakland study area, 343 in Los Angeles, and 232 in Sacramento, for a total of 933 households. On average, each household had five members, with the vast majority (89%) being home to either one or two children between the ages of 1 and 6 years. Most of the houses surveyed in all three areas were built before 1950 (89% in Oakland, 76% in the Sacramento area, and 53% in Los Angeles). Homes surveyed in the Oakland area were on average the oldest (mean = 1919), followed by Sacramento (mean = 1938), with the newest homes found in the Los Angeles survey area (mean = 1946).

Paint

Paint lead levels at houses surveyed are presented in Table 1. Indoor and outdoor paint samples were collected at approximately one-half of the Oakland houses, 80% of the Los Angeles houses, and almost all of the Sacramento houses surveyed (>94%). Two-thirds of the houses tested had interior paint lead levels measured from trim; 42 to 63% of the houses tested had exterior paint lead levels measured from trim. About one-half (48%) of the indoor paint samples were collected from living rooms. Analysis of variance found no statistically significant differences in geometric mean indoor paint lead levels by room sampled ($P > 0.05$ in each area).

Indoor and outdoor paint lead levels over all three areas ranged from 17 to 309,713 ppm and from 7 to 347,910 ppm, respectively. Geometric mean paint

lead levels in Oakland houses tested were more than 1.5 times greater than geometric mean paint lead levels in Sacramento and three to four times higher than in Los Angeles homes tested. The lowest average paint lead levels were in the Los Angeles survey area.

The distribution of interior and exterior paint lead levels by decade is depicted in Fig. 1. There is a trend toward lower median paint lead levels over more recent time, with a considerable range in paint lead levels in every decade. Median indoor paint lead levels decreased from 2827 ppm in pre-1920 houses to 200 ppm in post-1970 houses; for outdoor paint, median lead levels decreased from 31,406 to 440 ppm over this period. Exterior paint lead levels greater than 100,000 ppm were measured in every decade. The Spearman correlation coefficients for the relationship between lead in paint and age of housing were $r = -0.37$, $P < 0.01$ for interior paint and $r = -0.36$, $P < 0.01$ for exterior paint.

Current U.S. Housing and Urban Development Guidelines suggest an abatement action level of 5000 ppm (U.S. Department of Housing and Urban Development, 1990). Interior paint lead levels ≥ 5000 ppm were found in 31% of pre-1950 homes and 7% of post-1950 homes. The proportion of housing found to have exterior paint lead levels ≥ 5000 ppm is 71% for pre-1950 homes and 16% for post-1950 homes.

Paint on older homes was more deteriorated than paint on newer homes in Los Angeles and Sacramento. This relationship was statistically significant in Los Angeles ($P < 0.001$), but not in Sacramento ($P > 0.17$); Oakland did not have a sufficient number of newer homes for comparison. Paint samples were preferentially collected from nonintact paint. No relationship was found between interior paint condition and interior paint lead levels. There

TABLE 1
Paint Lead Levels at Houses Surveyed

	Oakland	Los Angeles	Sacramento	All Areas
Total houses surveyed	358	343	232	933
Interior paint (ppm)				
No. of houses sampled	188	280	222	690
Geometric mean	2540	817	1412	1327
± 1 standard deviation	308-20,962	145-4618	207-9611	188-9359
Median	4558	895	1284	1402
Range	25-309,713	20-100,960	17-201,014	17-309,713
Exterior paint (ppm)				
No. of houses sampled	213	266	219	698
Geometric mean	13,545	3100	8430	6654
± 1 standard deviation	1604-114,403	326-29,467	949-74,892	680-65,074
Median	22123	3456	12,168	9686
Range	7-347,910	9-216,174	57-320,834	7-347,910

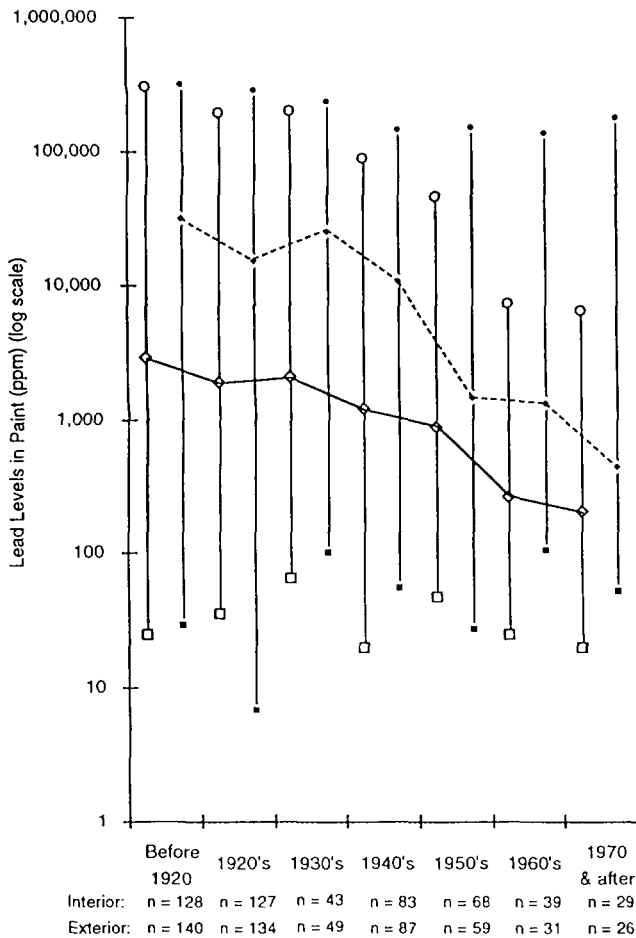


FIG. 1. Lead levels in interior and exterior paint in houses surveyed by year of construction (all three areas combined), median and range. ○, highest concentration interior paint; ◐, median interior paint; ◑, lowest concentration interior paint; ●, highest concentration exterior paint; ◐, median exterior paint; ◑, lowest concentration exterior paint.

was a small but statistically significant relationship between exterior paint condition and exterior paint lead levels for houses tested in Los Angeles and Sacramento, but not for houses tested in Oakland. The condition of paint and paint lead levels both were associated with age of housing. This suggests that newer homes in Oakland, with intact paint, may have been preferentially excluded from paint sampling. The number of newer homes surveyed in Oakland was too few to allow for testing for a relationship between housing age and condition of housing.

Preferentially sampling paint from trim may have increased the chance of finding lead paint for homes built between 1920 and 1959. Paint lead levels on trim were significantly higher than paint lead levels on walls for homes built between 1920 and 1959; there was no difference between paint lead levels on trim and walls in post-1959 homes. Among pre-1920 homes, interior, but not exterior, paint lead levels on

trim were significantly higher than those on walls ($P = 0.05$).

Approximately one out of four pre-1920 houses in Los Angeles and Sacramento was rated as having deteriorated interior paint (scored as 4 or 5); only one out of 10 post-1970 houses had this rating. For exterior paint, about one-half of the pre-1920 homes in Los Angeles were deteriorated and none of the post-1970 homes had this rating; one-third of the pre-1920 homes in Sacramento had deteriorated exterior paint compared to one-fifth of post-1970 homes.

Soil

Soil lead levels at houses surveyed are presented in Table 2. One or more soil samples were collected at 82% of the Oakland households surveyed and at more than 95% of the houses in both Los Angeles and Sacramento. Household soil lead levels ranged from 26 to 2664 ppm in the Los Angeles and Sacramento survey areas. Soil lead levels $\geq 10,000$ ppm were all collected in the Oakland survey area under rain drains and next to additional structures. Oakland household soil lead levels ranged from 56 to 88176 ppm. The geometric mean household soil lead level for Oakland houses was about four times higher than the geometric mean household soil lead level for houses tested in Los Angeles and Sacramento; geometric mean household soil lead levels were 897, 234, and 188 ppm for Oakland, Sacramento, and Los Angeles houses, respectively. Statistically, side-yard soil samples were significantly higher than front- and rear-yard samples in Oakland and Sacramento ($P < 0.01$ in each area), an average difference of 226 ppm in Oakland and 65 ppm in Sacramento. In Los Angeles, geometric mean lead levels in soil from every sampling location were virtually identical.

Soil lead levels were highly and significantly correlated with age of housing ($r = -0.64$, $P < 0.01$). Figure 2 presents the proportion of households with one or more soil lead samples ≥ 500 ppm by decade of construction for all areas combined. The proportion of houses having one or more soil samples ≥ 500 ppm declines from 86% for houses built before 1920 to 11% for houses built after 1970. Figure 3 presents the same relationship for houses in Oakland alone. In Oakland, the proportion of houses tested with one or more soil samples ≥ 500 ppm also declines among newer homes from 93% for homes built prior to 1920 to none in the only home built after 1970, but the majority (67%) of the houses built between 1950 and 1970 had one or more soil samples ≥ 500 ppm.

Many factors measured in this survey were thought *a priori* to increase the chance of having

TABLE 2
Lead Levels in Soil at Houses Surveyed

	Oakland	Los Angeles	Sacramento
Total houses surveyed	358	343	232
Household soil (ppm) ^a			
No. of houses sampled	292	327	227
Geometric mean	897	188	234
±1 standard deviation	370-2174	99-357	104-529
Median	880	190	229
Range	56-88,176	30-1973	26-2664
Front-yard soil (ppm)			
No. of houses sampled	231	290	221
Geometric mean	716	181	225
±1 standard deviation	313-1639	88-372	90-563
Median	680	178	222
Range	56-5827	17-1481	17-3795
Rear-yard soil (ppm)			
No. of houses sampled	141	236	197
Geometric mean	889	215	217
±1 standard deviation	377-2096	102-454	92-513
Median	789	203	198
Range	78-7175	31-8269	32-7770
Side-yard soil (ppm)			
No. of houses sampled	147	245	198
Geometric mean	942	203	290
±1 standard deviation	339-2221	88-467	99-846
Median	937	202	254
Range	57-6985	28-4554	11-12,094
Rain drain soil (ppm)			
No. of houses sampled	72	26	NS ^b
Geometric mean	1330	208	NS
±1 standard deviation	508-3479	96-453	NS
Median	1374	221	NS
Range	127-10,065	56-697	NS
Additional structure soil (ppm)			
No. of houses sampled	41	30	NS
Geometric mean	2766	196	NS
±1 standard deviation	316-24,253	100-382	NS
Median	1480	202	NS
Range	35-200,270	34-844	NS

^a Household soil lead level is defined as the geometric mean of the available front, rear, and side soil lead levels at each household sampled.

^b Not sampled.

high (≥ 500 ppm) soil lead levels, including year of housing construction, the concentration of lead in outdoor paint, and report of outdoor paint changes in the past year. To assess the independent influence of each of these factors on the odds of having a high soil lead level, multiple logistic regression was undertaken. Because historical lead emissions and other factors not measured by the survey were thought to vary by city, a variable designating the city where the household was located was also included in the final model as a surrogate for these unmeasured differences.

Figure 4 shows odds ratios and 95% confidence intervals for each of these factors after adjusting for the other factors in the model. Homes built prior to

1920 had 10 times the odds of having soil lead levels ≥ 500 ppm compared to post-1950 homes. Homes with exterior paint lead levels ≥ 5000 ppm were twice as likely to have soil lead levels in excess of 500 ppm. Oakland homes, after controlling for the influence of paint lead, age of housing, and exterior paint changes, were still 46 times more likely to have high soil lead levels than Los Angeles homes.

Dust

Dust lead levels at houses surveyed are presented in Table 3. Dust samples were collected at about 80% of the houses in the Los Angeles and Sacramento survey areas. Dust samples were not collected in Oakland. The concentration of lead in dust

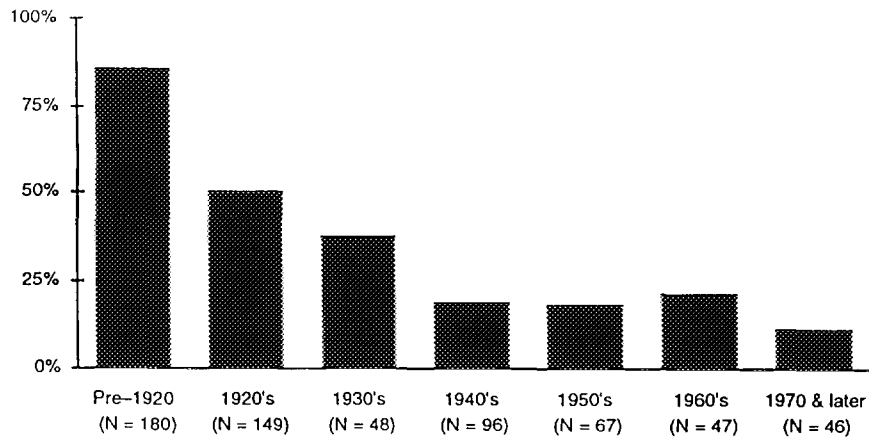


FIG. 2. Percentage of houses with one or more soil samples ≥ 500 ppm by year of construction (all areas combined).

ranged from 5 to 9537 ppm for both survey areas combined. Ninety-two percent of the dust samples in Los Angeles and 46% in Sacramento were collected from noncarpeted floors. Geometric mean lead dust concentration levels in the two areas were significantly different, with a geometric mean of 133 ppm for Los Angeles houses tested and 180 ppm for Sacramento houses ($P < 0.01$). Although the concentration of lead in dust was higher in Sacramento than Los Angeles, the mass of lead in a square meter area in houses in both areas was nearly identical; geometric mean lead loading was $26 \mu\text{g}/\text{m}^2$ in Los Angeles and $24 \mu\text{g}/\text{m}^2$ in Sacramento houses ($P = 0.66$).

Geometric mean dust lead concentration levels were significantly higher in Sacramento households reporting lead jobs: 287 ppm for houses where a lead worker lived ($N = 31$) compared to 164 ppm for houses with no lead worker ($N = 154$) ($P < 0.01$). No relationship between lead dust loading and lead-related jobs was demonstrated. In Los Angeles, lead in dust was not associated with job type of the household members. In both areas tested, lead in dust was not associated with hobbies.

Continuous variables measured in this survey expected to influence the lead levels in house dust include age of housing, lead levels in interior and exterior paint, and soil and paint deterioration. Spear-

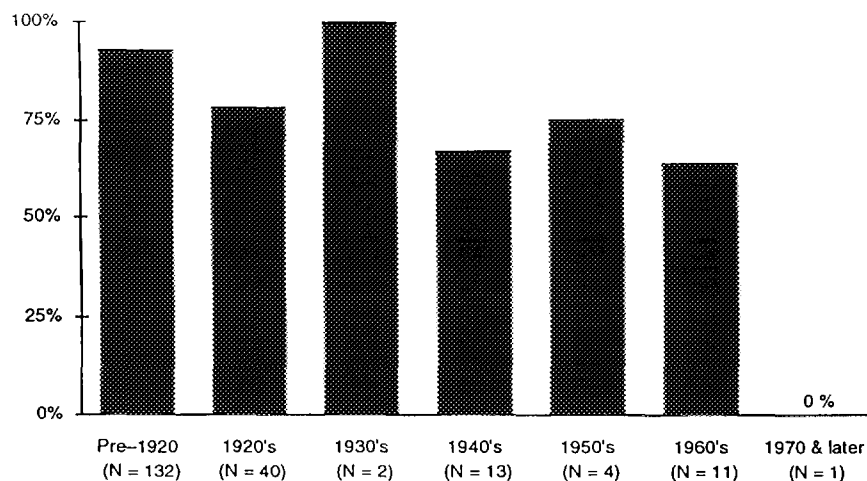


FIG. 3. Percentage of houses with one or more soil samples ≥ 500 ppm by year of construction (Oakland).

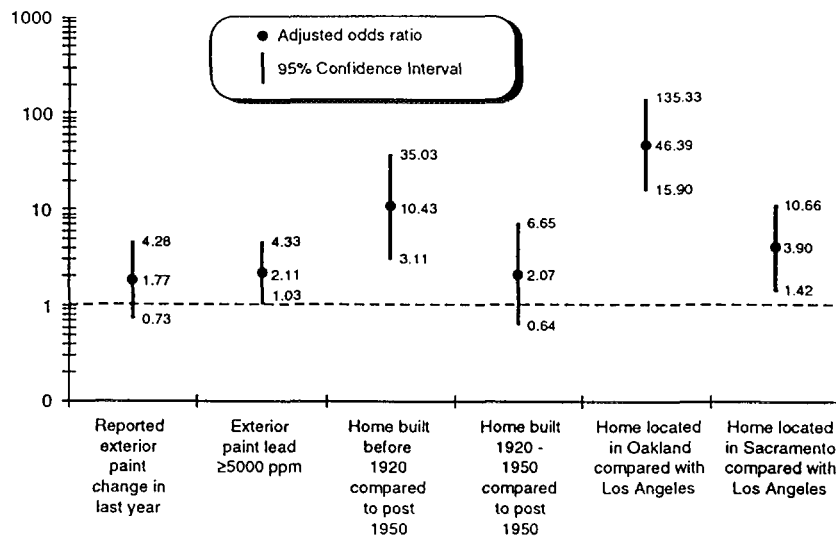


FIG. 4. Results of logistic regression modeling of soil lead levels ≥ 500 ppm: odds ratios and 95% confidence intervals.

man correlation coefficients for lead dust concentration levels and age of housing, interior paint, exterior paint, and soil were -0.34 , 0.19 , 0.29 , and 0.35 , respectively ($P < 0.01$ for each). These variables had little ability to explain dust lead loading levels measured. Spearman correlation coefficients for dust lead loading and age of housing, lead levels in interior paint, exterior paint, and soil were -0.20 , 0.12 , 0.15 , and 0.18 , respectively ($P \leq 0.02$). Among these four variables, interior paint lead levels had the weakest association with lead levels measured in dust (ppm or $\mu\text{g}/\text{m}^2$).

Interior paint condition was not associated with dust lead levels. There was a statistically significant but small relationship between exterior paint condition and lead dust concentration levels in Sacramento (Spearman correlational coefficient $r = 0.16$, $P = 0.03$) and lead dust loading levels in Los Ange-

les (Spearman correlational coefficient $r = 0.15$, $P = 0.02$). Households in Los Angeles reporting interior paint changes in the past year had geometric mean dust lead loading levels twice as high as in households not reporting paint changes ($47 \mu\text{g}/\text{m}^2$ compared to $23 \mu\text{g}/\text{m}^2$). No correlation between dust lead concentration levels and interior paint changes was demonstrated in either of the two communities tested.

Multiple logistic regression analysis of the relationship between the concentration of lead in household dust (the dependent variable) and each of five independent variables (year of housing construction, concentration of lead in soil, lead levels in indoor paint, lead jobs, and report of indoor paint changes in the past year) is presented in Fig. 5. Homes built before 1920, with exterior paint lead ≥ 5000 ppm, or having a lead worker residing in the home had sig-

TABLE 3
Lead Levels in Dust at Houses Surveyed

	Los Angeles	Sacramento	All Areas
Total houses	343	232	933
No. of houses sampled	275	188	463 ^a
Concentration of lead in dust (ppm)			
Geometric mean	133	180	151
± 1 standard deviation	47-377	79-411	57-397
Median	136	178	153
Range	5-9537	15-3105	5-9537
Lead loading in dust ($\mu\text{g}/\text{m}^2$)			
Geometric mean	26	24	25
± 1 standard deviation	5-120	5-105	5-114
Median	19	25	22
Range	3-3587	2-886	2-3587

^a Dust samples were not collected in the Oakland survey area.

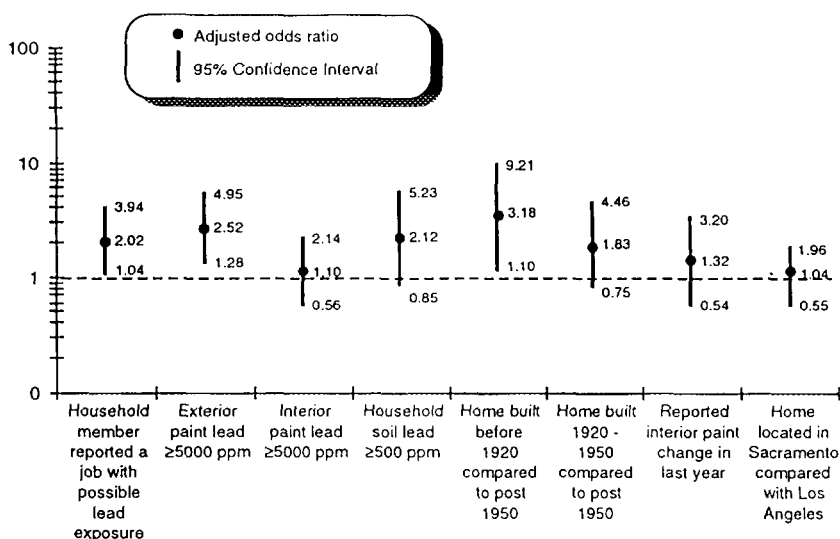


FIG. 5. Results of logistic regression modeling of dust lead concentrations ≥ 270 ppm: odds ratios and 95% confidence intervals.

nificantly increased chances of having high dust lead levels. Homes built before 1920 were three times more likely to have dust lead concentration at or above 270 ppm compared to post-1950 homes; homes built between 1920 and 1950 were about two times more likely to have higher dust lead levels. Households with members reporting a lead job were twice as likely to have high dust lead levels compared to houses with no one reporting a lead job. Households with exterior paint in excess of 5000 ppm were 2.6 times more likely to have elevated dust lead levels. Homes with high interior paint, however, were not more likely to have high dust lead levels.

Figure 6 shows the proportion of the variance explained by the multiple linear regression models. Factors measured by this survey explained 13% of the variance in dust lead concentration levels and 57% of the variance in soil lead concentration levels. Dust lead loading is a function of dust loading and dust lead concentration only. Two-thirds of the vari-

ance in dust lead loading levels were explained by dust loading and one-third by dust lead concentration.

Age of Housing

Age of the house surveyed was missing from the county assessor's data for about a third of the houses in Oakland and in Los Angeles. A comparison of geometric mean environmental lead levels at the homes for which age of housing was known to levels at the homes for which age of housing was missing found no difference in either Oakland or Los Angeles. This suggests that the missing values may be distributed among pre- and post-1950 houses in the same way as the houses for which age was known.

There was a higher proportion of pre-1950 houses among the houses surveyed than the proportion for the entire census tract clusters in the 1980 census data for the selected census tracts: 89% versus 72% for Oakland, 76% versus 66% for Sacramento, and 53% versus 46% for Oakland. Young children may

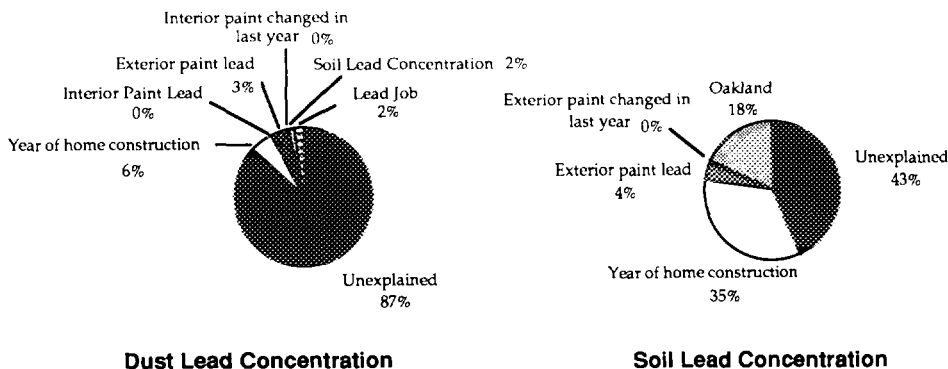


FIG. 6. Percentage of variance explained by multiple linear regression modeling.

live in older housing and/or there may be differences between the census and assessor's data. Census data determine age of housing by report of the census respondent; county assessors ascertain age of housing by data of the building permit. In the case of pre-1950 housing, building inspectors determined age of housing by locating permits that remained posted in the house and by evaluating the house's construction features.

DISCUSSION

The levels of lead found in paint in the houses surveyed reflect the historical use of lead in the formulation of paint. The highest average paint lead levels were among the oldest homes and in exterior paint. Before the 1940s, interior house paint in the United States typically contained lead in the range of 40 to 60% (400,000 to 600,000 ppm) (National Academy of Sciences, 1973). During the 1940s, some reduction in the amount of lead in interior residential paint occurred as the use of titanium dioxide began to replace lead pigments. In 1955, the paint industry adopted a voluntary 1% limit (10,000 ppm) on the concentration of lead in interior paints (HUD, 1990). Federal laws that limited the use of lead in interior and exterior paint were first enacted in the early 1970s. Congress banned the sale of interior and exterior paint containing $\geq 0.06\%$ (600 ppm) lead for residential use in 1977 by enacting the Consumer Product Safety Act (Federal Register, 1977).

The houses tested in this survey were mostly old, wood-frame and stucco bungalow-type residences, home to economically disadvantaged children in urban communities. Of the households surveyed 80% were rentals and 7% of the households reported receiving publicly funded housing subsidies. All three areas were near freeways and main streets. Thus, these areas were not selected to be typical for age of housing. Soil and dust lead levels in more affluent communities with older housing are probably lower than levels in these three high-risk communities surveyed. However, a national survey of the incidence of lead paint in housing conducted by HUD found "there are no significant differences in the incidence of lead-based paint by the income of the household, the value of the home, or the rent" (HUD, 1990). Therefore, it is probable that the presence of lead in interior and exterior paint may be comparable in more affluent communities with housing of the same age. The presence of lead paint represents a potential hazard in all housing because renovation activities and/or behavior of individual children may lead to exposures.

In 1990 California had 2.2 million pre-1950 and 9 million post-1950 homes (1990 U.S. Census). From this data it is estimated that 27% of the homes in California (or approximately 3 million households) may have exterior paint lead levels ≥ 5000 ppm, and 12% (or approximately 1.3 million homes) may have interior paint lead levels ≥ 5000 ppm. Because the number of post-1950 homes is so large, despite the higher prevalence of paint lead levels ≥ 5000 ppm before 1950, about half of the houses estimated to have both exterior and interior paint lead levels ≥ 5000 ppm were built after 1950.

Soil

High soil levels were measured at some homes in all three survey areas, and they were especially common in the homes tested in Oakland. Soil for disposal having lead levels ≥ 1000 ppm is classified as hazardous waste in California (California Code of Regulations, Title 22). These very high soil lead levels were present in yards of 46% of the houses tested in Oakland. Public health guidelines for lead levels in soil are in the range of 200 to 500 ppm (Madhavan *et al.*, 1989; California Department of Health Services, 1991; CDC, 1991). Household soil lead levels ≥ 200 ppm were measured in 45% of the households tested in Los Angeles, 57% in Sacramento, and 95% in Oakland. Eighty-five percent of the houses tested in Oakland had one or more soil samples ≥ 500 ppm lead, approximately the same proportion as identified in a 1976 survey in West Oakland (73%) (Przyborowski and Okamoto, 1976).

Soil lead levels measured next to homes (i.e., in the side yards) in Oakland and Sacramento were significantly higher than the front and rear yards, presumably due to lead paint and rain run-off. Households in Sacramento reporting exterior paint changes in the past year had geometric soil lead levels of 343 ppm, compared to 226 ppm for households reporting no exterior paint changes ($P = 0.02$), underscoring the need to contain dust during remodeling and abatement to prevent soil contamination.

Soil lead concentration levels in these urban communities are predicted by construction year, even after controlling for the measured presence of paint containing lead, which also contributed to soil lead levels. For soil lead levels, construction year is probably a measure of historical paint lead levels, the deterioration of paint, and the deposition of atmospheric lead in soil over time. Oakland homes had sharply higher odds of having elevated soil lead levels which could not be explained by paint lead levels or age of housing. This suggests that other unmeasured sources significantly influenced soil lead lev-

els in Oakland and shows that vast differences may exist among communities that are not measured by paint lead levels and age of housing.

Dust

This study underscores the importance of measuring lead dust concentration levels when determining the presence of lead hazards in houses. Sources of lead in the home (paint, soil, lead jobs) were more highly correlated with lead dust concentration levels than they were with lead dust loading levels. The significant differences in dust lead concentration levels between communities (and, by extension, between households) were not reflected in differences in dust lead loading levels, which were virtually identical in the two survey areas. These comparisons remained the same after examining the influence of floor type and the amount of dust collected on the results.

Dust lead loading is a measure of lead in the house dust and dust loading prior to sampling and, by definition, is a function of dust lead concentration and dust loading. This survey found that 67% of dust lead loading levels were explained by dust loading levels and 33% by dust lead concentration. Therefore, cleaning practices prior to sample collection, rather than sources of lead in the environment, would determine the amount of dust lead loading. Dust lead loading levels may not be as meaningful as dust lead concentration levels for risk assessment in the context of prioritizing lead paint abatement. Abatement activities should be linked to source reduction (primary prevention) and dust control practices should be considered universal recommendations to reduce exposure (a secondary prevention measure).

Measuring lead in house dust accurately and precisely is limited by the lack of an adequate sampling method. Moreover, the variability of dust lead levels over time and space is not captured by the dust sampling protocol used in this survey. These measurement errors are likely to have contributed to limited ability of multiple regression model to explain dust lead levels. Most of the variability in dust lead concentration levels could not be explained, underscoring the significant limitations of utilizing dust sampling results in exposure/risk assessment.

In this survey, dust lead concentration levels were predicted by age of housing and soil lead levels, with age of housing being the single best predictor of dust lead levels. Features of older homes that may enhance the dispersion and persistence of lead in house dust include the fact that older homes had significantly more deterioration of both interior and exte-

rior paint than newer homes and may have warped windows and doors (which may produce more friction when opened and closed) and crevices in floors where lead can presumably become lodged over time.

Surprisingly, interior paint lead levels had the weakest association of the variables expected to influence lead levels measured in dust (ppm or $\mu\text{g}/\text{m}^2$), and interior paint condition was not associated with dust lead levels. One possibility is that because the levels of lead in exterior paint tended to be higher than levels of lead inside the home, through track-in and windows, the higher levels of lead outside may contribute more to lead house dust lead levels than lower levels of lead in interior paint. Lower interior paint lead levels may also explain why reported paint changes did not appear to influence dust lead concentration levels.

CONCLUSIONS

Despite reductions in the amount of lead added to the environment over the past 20 years, the presence of lead and lead-containing paint is still very common in California's housing stock. Significant levels of lead remain in these high-risk communities in household paint, soil, and (consequently) house dust. The results underscore that for families with a lead worker, take-home exposure remains a significant source of lead in the home.

In general, the highest concentrations of lead in paint were found on exterior surfaces and, for homes built between 1920 and 1959, on trim. This finding indicates that efficient abatement interventions targeted to these highly concentrated sources would reap large reductions in the amount of lead in a household.

Age of housing is highly predictive of the presence of environmental lead levels and paint deterioration. In this survey age of housing was the best measured predictor of lead in soil and dust. However, although in general the probability of finding environmental lead diminishes for newer homes, high levels of lead were found in homes of all ages. The persistence of high lead levels in exterior paint and soil among post-1960 homes probably reflects the continued use of lead in exterior paint long after lead levels in interior paint were reduced, as well as the contribution of nonpaint sources to lead in soil. These results point out both the reliability and limitations of using age of housing as a predictor of environmental lead levels.

Risk assessment, for the purpose of determining abatement priorities for sources of lead in the environment, should not be linked to how much dust is

in the environment, but is more appropriately linked to measuring sources of lead directly and to dust lead concentration levels. Cautious interpretations of dust lead levels is essential.

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