The Prevalence of Lead-Based Paint Hazards in U.S. Housing

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In this study we estimated the number of housing units in the United States with lead-based paint and lead-based paint hazards. We included measurements of lead in intact and deteriorated paint, interior dust, and bare soil. A nationally representative, random sample of 831 housing units was evaluated in a survey between 1998 and 2000; the units and their occupants did not differ significantly from nationwide characteristics. Results indicate that 38 million housing units had lead-based paint, down from the 1990 estimate of 64 million. Twenty-four million had significant lead-based paint hazards. Of those with hazards, 1.2 million units housed low-income families (< $30,000/year) with children under 6 years of age. Although 17% of government-supported, low-income housing had hazards, 35% of all low-income housing had hazards. For households with incomes ≥ $30,000/year, 19% had hazards. Fourteen percent of all houses had significantly deteriorated lead-based paint, and 16% and 7%, respectively, had dust lead and soil lead levels above current standards of the U.S. Department of Housing and Urban Development and the U.S. Environmental Protection Agency. The prevalence of lead-based paint and hazards increases with age of housing, but most painted surfaces, even in older housing, do not have lead-based paint. Between 2% and 25% of painted building components were coated with lead-based paint. Housing in the Northeast and Midwest had about twice the prevalence of hazards compared with housing in the South and West. The greatest risk occurs in older units with lead-based paint hazards that either will be or are currently occupied by families with children under 6 years of age and are low-income and/or are undergoing renovation or maintenance that disturbs lead-based paint. This study also confirms projections made in 2000 by the President's Task Force on Environmental Health Risks and Safety Risks to Children of the number of houses with lead-based paint hazards. Public- and private-sector resources should be directed to units posing the greatest risk if future lead poisoning is to be prevented. *Key words:* **childhood lead poisoning, housing, housing survey, lead, lead-based paint, lead paint, lead poisoning prevention.** *Environ Health Perspect* **110:A599–A606 (2002). [Online 13 September 2002]**
http://ehpnet1.niehs.nih.gov/docs/2002/110pA599-A606jacobs/abstract.html

Lead is highly toxic, especially to young children. Excessive exposure causes reduced intelligence, impaired hearing, reduced stature, and many other adverse health effects (NAS 1993). The effects of lead toxicity have been well established, with clear evidence of harm found in children whose blood lead levels are above 10 μg/dL and some evidence that harm may occur at lower levels (CDC 1991; Lanphear et al. 2000; NAS 1993; Schwartz 1994; U.S. EPA 1990). A large body of evidence shows that a common source of lead exposure for children today is lead-based paint hazards in older housing and the contaminated dust and soil it generates (Bornschein et al. 1987; Clark et al. 1991; Jacobs 1995; Lanphear et al. 1995, 1998; Lanphear and Roghmann 1997; McElvaine et al. 1992; Rabinowitz et al. 1985; Shannon and Graef 1992), although other sources can be significant. Poisoning from lead-based paint has affected millions of children since this problem was first recognized more than 100 years ago (Gibson 1904; Turner 1897).

Children are exposed to lead from paint through two major pathways: either directly by eating paint chips (McElvaine et al. 1992) or indirectly by ingesting lead-contaminated house dust or soil through normal hand-to-mouth contact (Bornschein et al. 1987; Duggan and Inskip 1985; Lanphear and Roghmann 1997). Recent studies indicate that dust lead is the strongest predictor of childhood blood lead levels (Duggan and Inskip 1985; Lanphear et al. 1998). Unless proper precautions are implemented, lead-based paint can contaminate dust or soil when it deteriorates or is disturbed during maintenance, repainting, remodeling, demolition, or paint removal (Lanphear and Rogmann 1997; Rabinowitz et al. 1985; Shannon and Graef 1992). Residences with deteriorated lead-based paint are more likely to have higher levels of lead in house dust and the surrounding soil (Jacobs 1995; U.S. EPA 1995; U.S. HUD 1990).

Although lead in new residential paint was banned in the United States in 1978 by the Consumer Product Safety Commission (U.S. CPSC 1977a, 1977b; U.S. HUD 1997), a previous study conducted by the U.S. Department of Housing and Urban Development (HUD) in 1990 showed that lead-based paint still remained in an estimated 64 million dwelling units (U.S. EPA 1995; U.S. HUD 1990).

Recent studies of residential lead hazard controls have evaluated strategies that combined measures to remove and/or repair deteriorated lead-based paint, along with other measures to reduce and prevent reaccumulation of lead in dust. These treatments resulted in substantial and sustained reductions in interior lead dust and children's blood lead levels (Farfel et al. 1994; Galke et al. 2001; U.S. EPA 1997).

This study is part of the National Survey of Lead and Allergens in Housing and provides recent estimates of lead contamination in U.S. housing. It is part of a study that examines not only lead contamination but also allergen and endotoxin levels in U.S. housing. The allergen and endotoxin survey methodology has been published separately (Vojta et al. 2002).

Methods

The target population for this study consisted of the national housing stock of permanently occupied, noninstitutional housing units, including multifamily buildings, single-family housing, and manufactured housing (mobile homes) in all 50 states and the District of Columbia. Vacant housing, group quarters (e.g., prisons, hospitals, dormitories), hotels, motels, and other short-term housing, military bases, and housing where children are not permitted to live (e.g., housing designated exclusively for the elderly and those with zero bedroom units) were excluded. With these excluded, the eligible national housing stock consisted of approximately 96 million housing units out of approximately 112 million units. A nationally representative, random sample of 1,984 housing units was drawn from 75

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We thank the members of the hundreds of households who participated in this study and generously provided their time and access to their homes. We also thank the field interviewers and lead-based paint inspectors who collected the data and environmental samples.

This work was funded by the U.S. Department of Housing and Urban Development (HUD Contract C-OPC-21356) and the National Institute of Environmental Health Sciences (NIEHS). The survey plan was reviewed and approved by the institutional review boards of Westat and of the NIEHS.

Received 28 August 2001; accepted 5 March 2002.

randomly selected primary sampling units (PSUs), from which 831 eligible units and their occupants were recruited and completed the survey. (A PSU is a county or a cluster of contiguous counties, such as a metropolitan statistical area.) Documentation on using the data, and the data files themselves, are available at the HUD lead web site (U.S. HUD 2001, 2002). A comparison of the units in the study with national distributions of housing characteristics and socioeconomic and demographic factors from the 1997 American Housing Survey for the United States (U.S. Census Bureau 1997) and the 1998 and 1999 Current Population Surveys (U.S. Census Bureau 1999) showed that the units in this study did not differ significantly from nationwide characteristics (Table 1). Although the percentage of households in the sample with incomes below $20,000 and above $60,000 are both slightly below national estimates, the percentage of households in poverty is very close to the national estimates. It is possible that households with very low incomes (where the risk of lead poisoning is greatest) and with very high incomes (where the risk is lowest) may have been slightly undersampled.

A stratified sample of four rooms within each unit was drawn according to the following priorities: child's bedroom, common living area within the unit, kitchen, and one other random room. If no child's bedroom was present, another bedroom was selected according to a standard protocol. Table 2 presents the type and location of dust and soil samples and paint measurements made in each room, from the building exterior, and in the yard. Soil samples were collected from children's play areas at 375 housing units in 40 of the original 75 PSUs, and general yard samples were collected in all 75 PSUs. The 40 PSUs were randomly selected from the original 75 PSUs. Play area and yard area soil lead hazards are both included in the estimates of lead-based paint hazards reported here (see definition of "lead-based paint hazard" below). Weights were developed for housing units, rooms, yards, and exterior play yard areas to be nationally representative.

A standardized questionnaire was administered to an adult resident in each unit to determine age and renovation history of the unit; occupants' age, race and ethnic group, occupation, hobbies, and smoking patterns;

Table 1. Comparisons of the National Lead-Based Paint Survey population with the American Housing Survey (AHS) and the Current Population Survey (CPS).

Housing unit characteristic	No. estimated (thousands)	National Lead-Based Paint Survey estimates		Housing units in sample	AHS (1997) (%)[c]	CPS (1998–99)[c] (%)
		Percent estimated[a]	95% CI[b]			
Total housing units[d]	95,688	100		831		
Construction year						
1978–1998	29,774	31	30–32	220	30	
1960–1977	27,874	29	28–30	267	30	
1940–1959	20,564	21	20–23	186	20	
Before 1940	17,476	18	17–20	158	20	
Region						
Northeast	19,290	20	19–22	155	20	
Midwest	22,083	23	22–24	196	24	
South	35,474	37	36–39	277	35	
West	18,841	20	18–21	203	21	
Urbanization						
MSA ≥ 2 million population	26,814	28	24–32	276		30
MSA < 2 million population	45,753	48	43–53	417		47
Non-MSA	23,121	24	19–30	138		23
One or more children under age 18	36,994	39	38–39	398	37	
Refusal/don't know[e]	290			3		
Housing unit type						
Single family	82,651	86	84–89	705	88	
Multifamily	13,037	14	11–16	126	12	
Tenure						
Owner occupied	66,232	69	65–73	539		67
Renter occupied	29,074	30	27–34	289		33
Refusal/don't know[e]	381			3		
Household income ($30,000)						
< $30,000/year	33,830	35	30–41	309		40
≥ $30,000/year	56,111	59	54–63	482		60
Refusal/don't know[e]	5,747			40		
Household income ($20,000)						
$0–19,999/year	19,359	20	17–24	189		26
$20,000–39,999/year	25,855	27	23–31	228		27
$40,000–59,999/year	19,316	20	16–25	152		19
≥ $60,000/year	22,890	24	20–28	203		28
Refusal/don't know[e]	8,268			59		
Poverty						
In poverty	13,221	14	11–16	137		15
Not in poverty	76,336	80	77–82	651		85
Refusal/don't know[e]	6,130	6		43		
Race						
White	77,005	80	78–83	622	83	
African American	10,365	11	9–13	116	12	
Other[f]	6,571	7	5–8	77	6	
Refusal/don't know[e]	1,746	2		16		
Ethnicity						
Hispanic/Latino	7,434	8	6–10	86	9	
Not Hispanic/Latino	87,008	91	88–93	736	91	
Refusal/don't know[e]	1,246	1		9		

[a]All percentages are calculated with total housing units (95,688,000) as the denominator; percentages may not total 100% due to rounding. [b]CI = 95% confidence interval for the estimated number or percentage. [c]CPS data were taken from the 1998 CPS for household income and poverty measures and from the 1999 CPS for urbanization and tenure measures. [d]"Housing units" include permanently occupied, noninstitutional housing units in which children are permitted to live. [e]Refusals and "don't know" responses by survey respondents. [f]"Other" race includes Asian, American Indian or Alaskan Native, Native Hawaiian or other Pacific Islander, and more than one race.

household cleaning schedules; type of housing; types of heating, ventilating, and air conditioning systems; types of flooring; presence of pets; presence of pests; occupant income; government housing support; and other information. The responses to the questions on household size and income were used to apply the 1996 U.S. Census Bureau poverty thresholds (U.S. Census Bureau 1996) to determine whether or not a household was in poverty. The Census Bureau poverty income thresholds vary with household size.

Single-surface dust wipe samples were collected from floors, interior windowsills, and window troughs in accordance with the method in American Standards for Testing Materials (ASTM) E1728-95(ASTM 1995b). Paint measurements were made in a nondestructive manner using portable X-ray fluorescence (XRF) lead-based paint analyzers, in accordance with HUD procedures and the applicable Performance Characteristic Sheet (U.S. HUD 1997). A single commercial-brand of XRF instrumentation was used to minimize analytical error. Building components were tested in accordance with a standard procedure (Table 3). Soil samples were collected from the following areas: main entry, foundation/drip line, mid-yard area, and play areas (identified by the presence of play equipment or report from the adult occupant); if present, bare soil was sampled preferentially. Soil sampling was conducted in accordance with the method in ASTM E1727-95 (ASTM 1995a) using a core sample of the top one-half inch of soil, which is most accessible to children. All samples were collected by certified lead-based paint inspectors and analyzed in laboratories recognized under the National Lead Laboratory Accreditation Program of the U.S. Environmental Protection Agency (U.S. EPA) and accredited by the American Industrial Hygiene Association Environmental Lead Laboratory Accreditation Program. Detailed quality control/quality assurance protocols, laboratory analytical techniques, data management procedures, and a discussion of other potential sources of error (e.g., nonresponse bias and random sampling) have been reported elsewhere (U.S. HUD 2001).

Fieldwork for this survey was conducted between 1998 and 2000, with most units sampled during the warmer months. Dust lead levels may be slightly higher in the warmer months, due to increased track-in or other factors. Data presented here are not controlled for seasonal effects.

In this article, the term "lead-based paint hazard" is defined in the same way as in U.S. HUD and U.S. EPA regulations (U.S. EPA 2001; U.S. HUD 1999) (Table 4). A "significant lead-based paint hazard" means the area of deteriorated lead-based paint is above the *de minimis* levels (Table 5, note a) specified in the HUD regulations (U.S. HUD 1999) and/or that interior floor or windowsill dust lead or soil lead in the yard or play area meets or exceeds the levels established by the U.S. EPA. "Lead-based paint" is a paint or coating with a lead content ≥ 1 mg/cm^2 or 0.5% by weight (the same definition used in Title X of the 1992 Housing and Community Development Act, also known as the Residential Lead-Based Paint Hazard Reduction Act).

Table 2. Location and type of sample collected.

Rooms and sample type	Yard/play areas	Walls	Ceilings	Windows	Doors	Other trim	Floors
Kitchen							
Lead dust				X			X
Paint		X	X	X	X	X	X
Living room/family room							
Lead dust				X			X
Paint		X	X	X	X	X	X
Bedroom(s)							
Lead dust				X			X
Paint		X	X	X	X	X	X
Other random room(s)							
Lead dust				X			X
Paint		X	X	X	X	X	X
Major entrance							
Lead dust							X
Interior common area (multifamily only)							
Lead dust							X
Exterior							
Paint		X		X	X	X	
Soil	X						

Table 3. Paint testing locations.

Interior paint testing per room	Exterior paint testing
Wall—all four major walls	Siding—all four walls
Ceiling	Trim—two miscellaneous, one random wall
Door and related trim (if present)	Window and related trim—one random wall
Window and related trim (if present)	Door of major entrance to building
Baseboard	Porch and railing
Floor	Surfaces with deteriorated paint
Surfaces with deteriorated paint or friction areas	

Table 4. Type of lead-based paint hazard.

Type of hazard	No. housing units (thousands)[a] Estimate	95% CI[a]	Percent housing units[a] Estimate	95% CI
Significantly deteriorated lead-based paint	13,634	10,928–16,341	14	11–17
Interior lead-contaminated dust	15,468	12,982–17,954	16	14–19
Lead-contaminated soil	6,460	3,122–9,799	7	3–10
Any significant lead-based paint hazard	24,026	21,306–26,746	25	22–28
Any lead-based paint	37,897	34,521–41,272	40	36–43

[a]All percentages are calculated with total housing units (95,688,000) as the denominator; percentages may not total 100% due to rounding.

Results

Hazards. The results show that an estimated 25% of the nation's housing (equivalent to 24 million housing units) had significant lead-based paint hazards in the form of deteriorated paint, dust lead, or bare soil lead. The prevalence rates of significantly deteriorated lead-based paint and dust lead hazards were about the same—14% and 16%, respectively. Only 7% of houses had soil lead levels above current U.S. EPA/HUD standards (U.S. EPA 2001; U.S. HUD 1999) (Table 4).

The prevalence of lead-based paint hazards varies by region, housing unit age, household income, and other factors (Table 5). Of the units with significant lead-based paint hazards, an estimated 1.2 million units were occupied by low-income families (< $30,000/year) with children under 6 years of age. Among low-income households, 35% of the units had lead-based paint hazards, compared with 19% of units among households with middle and upper incomes (≥ $30,000/year). Seventeen percent of government-assisted, low-income housing had lead-based paint hazards, which is about the same as that for middle- and upper-income housing.

The prevalence of units with significant hazards varies with age of housing and region (Table 5), but less so with degree of urbanization. Housing built before 1960 had five to eight times the prevalence of hazards compared

with units built between 1960 and 1978. Approximately 36% of the housing in the Northeast and Midwest had lead-based paint hazards, compared with about 16% of housing in the South and West. Surprisingly, units in large urban and small urban and rural areas had roughly the same prevalance of lead-based paint hazards (~27%).

Rental units also had a slightly higher prevalence of lead-based paint hazards compared with owner-occupied units (30% and 23%, respectively).

This study also examined for the first time the prevalence of lead-based paint hazards in housing built after lead paint was banned in 1978. Among housing built between 1978 and 1998, 3% (1,042,000 housing units) had significant lead-based paint hazards, but 7% (2,031,000 housing units) may have had lead-based paint. (More than half of the XRF measurements above 1.0 mg/cm^2 in these newer units were on painted tile or stone substrates and are therefore uncertain because the lead may be in the substrates themselves, not the paint.)

Interior dust lead hazards. An estimated 16% of all housing units nationwide (equivalent to 15.5 million units) had one or more lead dust hazards on either floors or windowsills (Table 4). The geometric mean dust

Table 5. Prevalence of significant lead-based paint hazards in housing units (number and percent).[a]

Characteristics	No. housing units (thousands)			Percent housing units[c]		No. housing units in sample
	All housing units[b]	Units with hazards	95% CI[b]	Units with hazards	95% CI	
Total occupied housing units	95,688	24,026	21,306–26,746	25	22–28	831
Region						
Northeast	19,290	7,679	5,748–9,611	40	30–50	155
Midwest	22,083	7,250	6,402–8,097	33	29–37	196
South	35,474	6,191	4,964–7,419	17	14–21	277
West	18,841	2,906	1,856–3,956	15	10–21	203
Construction year						
1978–1998	29,774	1,042	169–1,915	3	1–6	220
1960–1977	27,874	2,340	1,445–3,235	8	6–12	267
1940–1959	20,564	8,826	6,720–10,933	43	32–51	186
Before 1940	17,476	11,818	10,045–13,591	68	56–75	158
One or more children < 6 years old						
All housing units	16,402	4,155	2,948–5,363	25	18–33	184
Units built 1978–1998	5,847	< 58[d]	—	< 1[d]	—	56
Units built 1960–1977	5,098	469	0–940	9	0–18	61
Units built 1940–1959	3,055	1,732	1,088–2,375	57	36–78	40
Units built before 1940	2,401	1,955	1,190–2,720	81	50–113[e]	27
Urbanization						
MSA ≥ 2 million population	26,814	6,793	4,978–8,609	25	19–32	276
MSA < 2 million population	45,753	10,232	8,171–12,293	22	18–27	417
Non-MSA	23,121	7,001	3,848–10,153	30	17–44	138
Housing unit type						
Single family	82,651	21,584	18,974–24,194	26	23–29	705
Multifamily	13,037	2,442	1,208–3,676	19	9–28	126
Occupant status						
Owner occupied	62,232	15,305	13,191–17,419	23	20–26	539
Renter occupied	29,074	8,721	6,583–10,859	30	23–37	289
Refusal/don't know[f]	381					3
Household income						
< $30,000/year	33,830	12,007	9,336–14,679	35	28–43	309
≥ $30,000/year	56,111	10,464	8,250–12,678	19	15–23	482
Refusal/don't know[f]	5,747					40
One or more children < 6 years old						
All income categories	16,402	4,155	2,948–5,363	25	18–33	184
< $30,000/year	4,791	1,201	600–1,801	25	13–38	61
≥ $30,000/year	11,236	2,860	1,763–3,957	25	16–35	117
Refusal/don't know[f]	375					6
Government support						
Government support	4,809	805	275–1,335	17	6–28	54
No government support	86,070	22,198	19,252–25,144	26	22–29	733
Refusal/don't know[f]	4,809					44
Poverty						
In poverty	13,221	4,976	3,458–6,494	38	26–49	137
Not in poverty	76,336	16,576	13,598–19,555	22	18–26	651
Refusal/don't know[f]	6,130					43
Race						
White	77,005	19,089	16,475–21,703	25	21–28	622
African American	10,365	2,969	1,807–4,131	29	17–40	116
Other[g]	6,571	1,496	672–2,321	23	10–35	77
Refusal/don't know[f]	1,746					16
Ethnicity						
Hispanic/Latino	7,434	2,399	1,235–3,564	32	17–48	86
Not Hispanic/Latino	87,008	21,196	18,674–23,719	24	21–27	736
Refusal/don't know[f]	1,246					9

[a]Significant lead-based paint hazard means a lead-based paint hazard above *de minimis* levels as defined in U.S. EPA and U.S. HUD regulations (U.S. EPA 2001; U.S. HUD 1999). The *de minimis* levels for paint deterioration are ≤ 20 ft^2 (exterior) or ≤ 2 ft^2 (interior) of lead-based paint on large surface area components (walls, doors), or damage to ≤ 10% of the total surface area of interior small surface area component types (windowsills, baseboards, trim). [b]All percentages are calculated with total housing units (95,688,000) as the denominator; percentages may not total 100% due to rounding; CI = 95% confidence interval for the estimated number or percentage. [c]All percentages are calculated with the "All housing units" column in each row used as the denominator. [d]No 1978–1998 housing units with one or more children < 6 years old in this sample have lead-based paint hazards. [e]Upper 95%CI value > 100% reflects uncertainty in number of housing units in first data column. [f]Refusals and "don't know" responses by survey respondents. [g]"Other" race includes Asian, American Indian or Alaskan Native, Native Hawaiian or other Pacific Islander, and more than one race.

lead level for floors, window sills, and window troughs was 1.1 μg/ft^2, 9.4 μg/ft^2, and 96.4 μg/ft^2, respectively (Table 6). The arithmetic means (used for composite dust sampling) for these surfaces were 13.6 μg/ft^2, 195 μg/ft^2, and 1,991 μg/ft^2, respectively. These can be compared with the current U.S. EPA/HUD dust lead hazard or clearance standards for these surfaces, which are 40 μg/ft^2, 250 μg/ft^2, and 400 μg/ft^2, respectively (U.S. EPA 2001; U.S. HUD 1999).

Dust lead hazards are more likely to exist in homes with significantly deteriorated interior lead-based paint. Although only one-third of homes with interior lead-based paint in good condition had dust lead hazards, nearly two-thirds of the homes with deteriorated interior lead-based paint had dust lead hazards (Table 7). Based on our results, of the 24 million units with lead-based paint hazards, 2.7 million units with no lead-based paint on either the interior or exterior at the time of the survey have dust lead hazards. Of the 2.7 million housing units with dust lead hazards but no intact or deteriorated lead-based paint, approximately 270,000 units had soil lead hazards, and occupants in another 700,000 units reported having a lead hobby or an occupation potentially using lead, all of which can contribute to interior dust lead levels.

Bare soil lead hazards. An estimated 5% (~4.9 million) of housing units nationwide had play area soil lead levels ≥ 400 ppm, the current U.S. EPA/HUD standard (U.S. EPA 2001; U.S. HUD 1999) (Table 8). Among all housing unit yard areas, 7% (~6.3 million) have bare soil lead levels ≥ 1,200 ppm, the current U.S. EPA/HUD standard outside of play areas (U.S. EPA 2001; U.S. HUD 1999) (Table 9). Soil lead levels are also related to deteriorated exterior lead-based paint. Comparing units with and without deteriorated exterior lead-based paint, the percentage of units with bare soil lead levels ≥ 1,200 ppm decreases from 24% to only 4%, respectively (Table 10).

Lead-based paint. Our results indicate that 38 million units have lead-based paint somewhere in the interior or on the exterior of the unit (Table 4). The influences of age, demographic, and socioeconomic factors on the presence of lead-based paint are similar to those presented in Table 5 for significant lead-based paint hazards. Although 40% of housing units had lead-based paint somewhere, most surfaces, even in older housing stock, did not have lead-based paint (Table 11). In post-1960 housing, only 0–2% of interior surfaces had lead-based paint, whereas 0–12% of exterior surfaces had lead-based paint. Even in older pre-1940 housing, only 7–22% of interior surfaces and 24–41% of exterior surfaces had lead-based paint. In almost all age categories for both interior and exterior surfaces, the building components with the highest prevalence of lead-based paint were windows and doors. These are friction and impact surfaces that can generate significant levels of lead dust and paint chips.

For all housing units, we estimate 7.5 billion ft^2 of interior lead-based paint and 29.2 billion ft^2 on exterior surfaces, roughly 2% and 22% of the total interior and exterior painted surfaces, respectively. On average, for each housing unit with lead-based paint, there are 259 ft^2 of lead-based paint on interior surfaces and 996 ft^2 on exterior surfaces (Table 12).

A comparison of the 1990 HUD survey (U.S. EPA 1995; U.S. HUD 1990) with this study shows that the number of units with lead-based paint fell from 64 million units in 1990 to 38 million in 2000 (Tables 4 and 13). Some possible reasons for this decline are discussed below.

Discussion

The results show that despite considerable progress, significant lead-based paint hazards remain prevalent, existing in 25% of all U.S. housing. The association between lead-based

Table 6. Dust lead loadings on floors and windows.

Statistic	Floors (μg/ft^2)	Windowsills (μg/ft^2)	Window troughs (μg/ft^2)
Arithmetic mean	13.6	194.9	1,990.9
Arithmetic SD	483.5	1,682.7	12,086.5
Geometric mean	1.1	9.4	96.4
Geometric SD[a]	3.8	9.3	14.4
25th percentile	0.375	2.0	18.0
Median	0.9	8.3	89.1
75th percentile	2.0	37.13	462.0
90th percentile	6.0	172.8	2,824.2
95th percentile	13.2	524.9	6,974.6
HUD/EPA standards	40	250	NA
No. samples	3,894	2,302	1,607

NA, not applicable. For this table, zero and negative values were set to 0.375.
[a]The geometric standard deviation is computed as exp(*s*), where *s* is the arithmetic standard deviation of the natural logarithms of the loadings (e.g., Gilbert 1987).

Table 7. Association between dust lead hazards and presence and condition of interior lead-based paint (all housing unit ages, thousands of units).

	No lead-based paint on interior or exterior		No interior lead-based paint[a]		Interior lead-based paint in good condition		Significantly deteriorated interior lead-based paint	
Characteristic	No.	Percent	No.	Percent	No.	Percent	No.	Percent
No interior dust lead hazards								
Estimate[b]	55,105	95	62,752	94	15,244	67	2,389	39
Lower 95% CI[c]	51,893	90	60,141	90	12,633	56	1,565	26
Upper 95% CI	58,318	100	65,363	98	17,855	78	3,213	53
Interior dust lead hazards								
Estimate[b]	2,686	5	4,068	6	7,508	33	3,727	61
Lower 95% CI	1,372	2	2,584	4	6,024	26	2,505	41
Upper 95% CI	4,001	7	5,552	8	8,992	40	4,949	81
Total housing units	57,791	100	66,820	100	22,752	100	6,116	100

[a]Includes houses with only exterior lead-based paint. [b]Estimate is either the number of permanently occupied, noninstitutional housing units in which children are permitted to live, or the percentage of total housing units. [c]CI, 95% confidence interval for the estimated number or percentage.

Table 8. Distribution of bare soil lead concentrations in children's play areas.

Bare play area soil lead levels (ppm)	No. housing units (thousands)[a]		Percent housing units[b]		Housing units (*n*)
	Estimate	95% CI[a]	Estimate	95% CI	
≥ 0	76,404	69,826–82,982	80	73–87	294
≥ 20	49,019	42,946–55,092	51	45–58	209
≥ 50	28,878	25,828–31,929	30	27–33	127
≥ 200	10,849	7,899–13,800	11	8–14	101
≥ 400[c]	4,856	2,096–7,616	5	2–8	84
≥ 1,200	2,493	458–4,529	3	1–5	82
≥ 1,600	2,078	92–4,063	2	0–4	80
≥ 2,000	1,777	0–3,871	2	0–4	77
≥ 5,000	380	0–1,231	0	0–1	1
No play area	12,368	6,659–18,077	13	7–19	53
Missing[d]	6,916	1,862–11,969	7	2–13	23
Total	95,688		100		375

[a]All percentages are calculated with total housing units (95,688,000) as the denominator; percentages may not total 100% due to rounding. [b]All percentages are calculated with total housing units (95,688,000) as the denominator. [c]U.S. EPA standard for play areas. [d]Missing means that soil was present but no lead value is available (usually due to inaccessibility or respondent refusal).

paint, lead-contaminated dust, and lead-contaminated soil is consistent with the 1990 HUD survey. Yet 2.7 million homes without lead-based paint had dust lead hazards at the time of the recent survey. However, the fact that lead-based paint was not found in these homes at the time of the survey does not necessarily mean it had never been present at some time in the past. Ongoing housing rehabilitation, maintenance, and repainting all tend to remove lead-based painted surfaces but may leave behind dust lead hazards. Also, some lead-contaminated dust may be from lead-contaminated soil tracked into homes. Although some dust lead may be due to aerosol deposition from ambient air, air lead levels in the United States have declined greatly with the phaseout of leaded gasoline. It is also possible that lead-contaminated dust can originate from lead-based paint in nearby dwellings that are undergoing rehabilitation, maintenance, or repainting. Additionally, some of the lead hobbies or occupations reported by occupants could produce a lead dust hazard. In any case, Table 7 shows that the vast majority of houses with dust lead hazards have lead-based paint on either the interior or exterior, and that houses with deteriorated lead-based paint are far more likely to have dust lead hazards. Further research is needed to identify other potential sources of dust lead hazards.

The apparent decrease in the number of units with lead-based paint over the past decade was greater than expected, declining from about 64 million (or 83%) of pre-1980 housing units to 38 million (or 40%) of all 96 million housing units in the sampling frame of this study, a decline of 26 million units. A number of factors that likely contributed to this apparent decline are discussed below.

Ongoing lead hazard control activities. The number of units undergoing lead hazard control likely increased over the past decade because of HUD's lead hazard control grants to local governments; other similar local, state, and federal lead hazard control programs; lead hazard control requirements in HUD's public housing program and federally assisted housing programs; promulgation and enforcement of the U.S. EPA/HUD lead-based paint disclosure regulation (U.S. HUD and U.S. EPA 1996); and increased public awareness of lead-based paint hazards, which likely resulted in privately funded lead hazard control activities. The effect of public education (carried out largely through federal, state, and local programs) in prompting lead hazard control efforts is difficult to quantify but may be much larger than is currently understood.

Demolition and renovation. Although demolition, remodeling, and renovation activities are known to increase exposures in the short run if lead-safe work practices are not used, they reduce both the number of units and the number of surfaces within units with lead-based paint over the long run. Over the past 5 years, standardized curricula and training courses have been developed to educate the work force on lead-safe work practices, and the U.S. EPA has promulgated a final rule regarding public education prior to certain renovation practices (U.S. EPA 1998). This educational effort should reduce the generation of lead-contaminated dust during renovation and maintenance.

It is widely assumed that the phaseout of lead in gasoline and lead in food canning are primarily responsible for most of the decline in population blood lead levels over the past several decades (along with regulation of lead in water and industrial emissions). But it is likely that housing rehabilitation, maintenance, and demolition also had a significant impact over the same time period. The President's Task Force on Environmental Health Risks and Safety Risks to Children (2000) used data from the American Housing Survey and other sources to estimate the size of this effect during the 1990s. Those data show that older units with lead-based paint are more likely to undergo rehabilitation or demolition than are newer houses. From 1989 to 1999, the number of pre-1940 units declined by 2.8% annually, the number of 1940–1959 units declined by 2.65% annually, and those from 1960–1974 declined by 2.1% annually. In short, from 1989 to 1999, the number of units with lead-based paint declined by a total of about 10 million units due to housing demolition and renovation alone (Appendix to the President's Task Force Report 2000). This same pattern likely occurred during earlier decades as well, contributing to the overall decline in population blood lead levels in ways not previously recognized.

Improvements in laboratory and XRF technology and quality control. This study used an XRF model that is both more precise and more

Table 9. Distribution of bare soil lead concentration in entire yard by construction year.

Bare soil lead concentration (ppm)	No. housing units (thousands)[a] All years	Before 1940	1940–1959	1960–1977	1978–1998	Percent housing units[b] All years	Before 1940	1940–1959	1960–1977	1978–1998
≥ 0	77,888	12,015	16,843	23,185	25,845	81	69	82	83	87
≥ 20	55,114	12,015	15,404	17,345	10,350	58	69	75	62	35
≥ 50	40,023	11,193	12,789	10,437	5,603	42	64	62	37	19
≥ 200	15,299	7,243	6,073	1,793	190	16	41	30	6	1
≥ 400	9,996	5,148	3,736	1,111	0	10	30	18	4	0
≥ 1,200[c]	6,271	3,386	2,886	0	0	7	19	14	0	0
≥ 1,600	3,900	2,006	1,894	0	0	4	12	9	0	0
≥ 2,000	3,124	1,320	1,804	0	0	3	8	9	0	0
≥ 5,000	1,580	1,106	475	0	0	2	6	2	0	0
Missing[d]	145	145	0	0	0	2	1	0	0	0
No bare soil	15,413	4,313	2,762	4,613	3,724	16	25	13	17	13
No soil[e]	2,242	1,003	939	95	205	2	6	5	0	1
Total	95,688	17,476	20,544	27,893	29,774	100	100	100	100	100

[a]"Housing units" include permanently occupied, noninstitutional housing units in which children are permitted to live. [b]All percentages are calculated with total housing units of that age as the common denominator. [c]U.S. EPA standard for yards. [d]"Missing" means that soil was present but no lead value is available (usually due to inaccessibility or respondent refusal). [e]"No soil" means that there was no soil on the property to sample.

Table 10. Association between bare soil lead concentration and housing units with or without deteriorated exterior lead-based paint.

Bare soil lead concentration (ppm)	Without any lead-based paint Percent	95% CI	Without significantly deteriorated exterior lead-based paint[a,b] Percent	95% CI[a]	With significantly deteriorated exterior lead-based paint[a,b] Percent	95% CI
≥ 0	83	78–88	83	77–88	73	55–92
≥ 20	49	41–56	56	48–63	73	54–92
≥ 50	28	20–36	38	30–47	67	51–83
≥ 200	5	1–9	13	9–17	39	19–58
≥ 400	3	0–5	8	5–11	30	11–49
≥ 1,200	1	0–3	4	2–7	24	7–41
≥ 1,600	1	0–3	2	1–4	17	4–30
≥ 2,000	1	0–2	2	0–4	13	2–24
≥ 5,000	0	0–0	1	0–2	8	0–17
Missing[c]	0	0–0	30	0–0	1	0–5
No bare soil	14	10–19	15	11–20	22	3–41
No soil[d]	3	0–6	2	0–4	4	0–9
Total	100		100		100	

[a]All percentages are calculated with total housing units (95,688) as the denominator; percentages may not total 100% due to rounding. [b]Percentages are calculated with the number of housing units without any lead-based paint, and with and without deteriorated lead-based paint, 57,791,000, 11,473,000 and 84,215,000, respectively, as the denominators. [c]"Missing" means that soil was present but no lead value is available (usually due to inaccessibility or respondent refusal). [d]"No soil" means that there was no soil on the property to sample.

accurate than the instrument used in 1990 (U.S. HUD 1990). Over the past decade, Performance Characteristics Sheets defining acceptable tolerance limits for all commercially available instruments have been published (U.S. HUD 1997), which has spurred the introduction of a new generation of more precise and accurate lead-based paint analyzers, one of which was used in this study. In addition, all states now have certification (licensing) laws (or are covered by the U.S. EPA) for lead-based paint inspectors (U.S. EPA 1996); in 1990, only one state had such a law. All of this makes it less likely to misclassify a surface with lead-based paint in the more recent survey.

Larger sample size. The recent study sampled more units (831 vs. 284), more rooms within units (4–6 rooms vs. 2 rooms), and completed more measurements within rooms, compared to the 1990 survey (U.S. HUD 1990), making these estimates more precise and accurate. The larger number of measurements would be expected to increase the number of homes with lead-based paint, contrary to the findings above, if the number of units with lead-based paint in fact had remained the same. There may be other methodologic differences in the two surveys that could explain some of the observed decline, which will be explored in future papers.

Other key findings. Differences in the definition of what constitutes a lead-based paint hazard and the protocols to measure lead in dust and soil changed greatly between the two surveys, making a direct comparison of hazard prevalence problematic. The percentage of housing units with deteriorated lead-based paint actually increased slightly, from 19% in 1990 to 22% in the present study (Table 13). Although the difference did not reach statistical significance, such an increase could reflect continued aging of the housing stock and changes in the definition of paint deterioration used in the two studies. If the prevalence of deteriorated paint either increased or remained constant over the past decade, additional efforts are needed to maintain lead-based paint in a way that ensures that it does not deteriorate and present new hazards.

This study shows that most painted surfaces, even in older housing, are not coated with lead-based paint. Use of lead-safe work practices on surfaces with lead-based paint is essential in order to minimize dust, paint chips, and contaminated soil that may be generated during maintenance and housing rehabilitation activities, because only a small amount of lead-based paint is needed to produce very high dust lead levels. For example, if sanded and turned into contaminated dust that is spread across an average-size room, only 1 ft^2 of paint at a lead concentration of 1 mg/cm^2 (the federal standard) is needed to produce a settled dust lead level of 9,300 $\mu g/ft^2$, several orders of magnitude above current dust lead standards (U.S. HUD 1995).

This study also suggests that rental properties are somewhat more likely to have lead-based paint hazards than are owner-occupied properties (30% vs. 23%, respectively), perhaps because of the increased turnover rates and lower maintenance levels that may be more common in rental units. Thus, efforts to increase homeownership may also serve to reduce the prevalence of childhood lead poisoning.

Although it has been widely assumed that large cities have a higher prevalence of lead-based paint hazards than do smaller ones, these data show that urban and rural areas both have roughly the same prevalence—about 26% (Table 5). These results suggest that greater attention may need to be given to rural housing, although large cities clearly have more units with lead-based paint hazards within relatively small geographic areas.

The percentage of building components coated with lead-based paint in housing built after the 1978 ban is 0–3% (Table 11). This suggests that the ban was not immediately effective in removing stocks of lead-based paint from retail and wholesale outlets. It also suggests that there may be continuing use of industrial or marine lead-based paint, which is still available, in housing. The fact that about half of the XRF readings indicating a lead concentration greater than 1 mg/cm^2 were taken on tiled surfaces means that the percentage of surfaces with lead-based paint in newer housing is between 1% and 2%. It is not known whether lead was actually present in the tile itself or in the glazing of the tile, or

Table 11. Building components coated with lead-based paint by year of construction (%).

Component type	All years	1978–1998	1960–1977	1940–1959	Before 1940
Interior					
Walls, floors, ceilings	2	0	1	2	7
Windows	9	1	2	6	21
Doors	7	0	1	7	22
Trim	5	0	2	4	15
Other	4	0	1	2	12
Exterior					
Walls	14	0	9	18	34
Windows	25	0	12	30	41
Doors	15	2	5	29	33
Trim	11	3	8	16	24
Porch	15	1	7	25	28
Other	18	0	8	37	37

Table 12. Surface area of lead-based paint.

Component	National total surface area of lead-based paint		Avg surface area per housing unit (ft^2)
	Square feet (billions)	Paint on component (%)	
Interior			
Wall, floor, ceiling	4,993	2	173
Window	687	9	24
Door	911	6	32
Trim	499	5	17
Cabinets, chimney, beams	388	2	13
Total	7,448	2	259
Exterior			
Wall	26,706	18	912
Window	365	28	12
Door	446	14	15
Trim	556	12	19
Porch	1,086	21	37
Total	29,159	22	996

Avg, average.

Table 13. Comparison of the prevalence of lead-based paint[a] to that in the 1990 HUD survey (housing units built before 1980).

Location and condition of lead-based paint	1990 HUD survey		2000 HUD national survey[b]	
	No.[c]	Percent	No.[c]	Percent
Housing units built before 1980	77,177	100	68,756	100
Units with lead-based paint	64,059	83	34,195	50
Interior lead-based paint	48,986	63	26,184	38
Exterior lead-based paint	56,495	73	27,373	40
Units with deteriorated lead-based paint[a]	14,354	19	14,962	22
Interior deteriorated lead-based paint	5,596	7	7,281	11
Exterior deteriorated lead-based paint	9,657	13	11,784	17

[a]Deteriorated lead-based paint is as defined in U.S. HUD (1995). [b]All the data in this table are restricted to housing built before 1980. [c]Thousands of housing units.

whether it was an instrumentation artifact. Furthermore, it is not known whether tile poses a significant source of lead exposure to children. Further analyses of the prospect of continuing contamination of U.S. housing through new application of lead-based paint and the nature and importance of lead in tile are both needed. Nevertheless, it is clear that lead-based paint hazards in housing built after 1978 are very rare.

Conclusion

This study shows that despite a large decline in the number of housing units with lead-based paint from 1990 to 2000, there are still millions remaining with hazards. Resources should be directed to those most likely to cause childhood lead poisoning: older housing units with lead-based paint hazards that are occupied by (or likely to be occupied by) children under 6 years of age and are low-income and/or are undergoing certain housing rehabilitation or maintenance that disturbs surfaces coated with lead-based paint. Hazard controls should focus on deteriorated lead-based paint, windows, doors, dust, and bare soil in play areas. Window replacement also has other important benefits, such as energy conservation.

This study confirms a prediction released by the President's Task Force in February 2000. That forecast indicated that based on trends in demolition, housing rehabilitation, lead hazard control, and other factors, the number of units with lead-based paint hazards in 1999 could be expected to be 24 million. This study found that the actual number is 24 ± 2.7 million units, making the task force estimate well within the confidence interval of this survey. The task force report indicated that private and public expenditures for the incremental cost of lead hazard control totaling approximately $230 million per year for 10 years would be needed to virtually eliminate childhood lead-based paint poisoning and realize a net benefit of $890 million per year for 10 years from avoided childhood lead-poisoning cases. This cost analysis factors in ongoing housing rehabilitation, maintenance, and lead hazard control, as well as regulation of federally assisted low-income housing. Further efforts are needed to improve maintenance standards by incorporating lead-safe work practices into routine housing operations, especially in low-income housing.

Further efforts are also needed to educate maintenance and housing rehabilitation workers, property owners, parents, and others to help ensure that lead-based paint remaining in millions of houses does not become hazardous and pose future risks to millions of children born into or occupying such houses in the coming decades.

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