

A Study of Urban Housing Demolitions as Sources of Lead in Ambient Dust: Demolition Practices and Exterior Dust Fall

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Demolition of older housing for urban redevelopment purposes benefits communities by removing housing with lead paint and dust hazards and by creating spaces for lead paint-free housing and other community resources. This study was conducted to assess changes, if any, in ambient dust lead levels associated with demolition of blocks of older lead-containing row houses in Baltimore, Maryland (USA). In this article we present results based on dust-fall samples collected from fixed locations within 10 m of three demolition sites. In subsequent reports we will describe dust lead changes on streets, sidewalks, and residential floors within 100 m of the demolition sites. Geometric mean (GM) lead dust-fall rate increased by > 40-fold during demolition to 410 $\mu\text{g Pb/m}^2/\text{hr}$ (2,700 $\mu\text{g Pb/m}^2$ per typical work day) and by > 6-fold during debris removal to 61 $\mu\text{g Pb/m}^2/\text{hr}$ (440 $\mu\text{g Pb/m}^2$ per typical work day). Lead concentrations in dust fall also increased during demolition (GM, 2,600 mg/kg) and debris removal (GM, 1,500 mg/kg) compared with baseline (GM, 950 mg/kg). In the absence of dust-fall standards, the results were compared with the U.S. Environmental Protection Agency's (U.S. EPA's) dust-lead surface loading standard for interior residential floors (40 $\mu\text{g}/\text{ft}^2$, equivalent to 431 $\mu\text{g}/\text{m}^2$); daily lead dust fall during demolition exceeded the U.S. EPA floor standard by 6-fold on average and as much as 81-fold on an individual sample basis. Dust fall is of public health concern because it settles on surfaces and becomes a pathway of ambient lead exposure and a potential pathway of residential exposure via tracking and blowing of exterior dust. The findings highlight the need to minimize demolition lead deposition and to educate urban planners, contractors, health agencies, and the public about lead and other community concerns so that society can maximize the benefits of future demolition activities nationwide. **Key words:** demolition, demolition practices, dust fall, dust lead, environment, lead, lead sources, urban housing, urban redevelopment. *Environ Health Perspect* 111:1228–1234 (2003). doi:10.1289/ehp.5861 available via <http://dx.doi.org/> [Online 1 April 2003]

Demolition of aging and derelict housing is one component of redevelopment and revitalization efforts under way in America's inner cities. During this decade, the U.S. Department of Housing and Urban Development (HUD) estimates that 1.8 million older housing units will be demolished nationwide (President's Task Force 2000). Demolition can eliminate housing with high amounts of lead in paint and dust and create open spaces for the development of new housing free of lead paint and for other community projects. Our earlier work showed that new housing clusters built on past demolition sites in older urban areas after the 1978 federal ban on lead in residential paint were associated with low levels of lead in house dust and children's blood (U.S. EPA 1997a).

These benefits notwithstanding, it is important to understand the risks associated with the demolition of housing containing lead in paint and dust, particularly in older urban neighborhoods where children are already at high risk of lead poisoning [Centers for Disease Control and Prevention (CDC) 2000]. Because older housing is likely to contain lead in paint and dust (Jacobs et al. 2002), demolition of older housing represents a potentially large source of dispersed lead in urban environments. We observed the dispersion of large

amounts of visible dust into the air, streets, and sidewalks when blocks of older (pre-1950) row houses were demolished in low-income minority neighborhoods of Baltimore, Maryland. Few data are available on changes in ambient and residential lead levels associated with the demolition of older houses. One small study found that demolition was associated with increased dust lead loadings in neighboring houses, particularly when demolition was performed without wetting (Diorio 1999). A review of the literature and conversations with experts at various federal and state agencies revealed little relevant information regarding the specific risks of lead exposure in neighborhoods in the vicinities of residential demolition sites. Studies have documented lead exposures associated with the removal of lead-based paint from bridges and other steel structures (Bareford and Record 1982; Landrigan et al. 1982).

A longitudinal field study of three residential demolition sites in Baltimore was planned and conducted in collaboration with the Historic East Baltimore Community Action Coalition (HEBCAC), the agency coordinating housing and economic redevelopment activities in a portion of the East Baltimore Empowerment Zone. The demolition activities

studied in this research were planned and performed by other entities as part of ongoing redevelopment efforts in the HEBCAC area and were not initiated for the purposes of this study. The study protocol and consent forms were reviewed and approved by the institutional review board of the Johns Hopkins Medical Institutions.

In this article we describe the study sites, demolition processes, changes in exterior dust-fall lead loadings, and concentrations in close proximity to the demolition sites (within 10 m) and discuss the public health significance of the findings and implications for future demolition activities. Future reports will describe changes in lead levels in settled dust from streets, sidewalks, and floors in houses within a radius of 100 m (~2 blocks) from the demolition sites.

Materials and Methods

Study sites. The three demolition sites selected for study were all located within 1 km of each other in low-income neighborhoods undergoing urban redevelopment. Selection criteria were as follows: demolition was performed using typical practices on residential blocks built before 1950 and likely to contain lead paint based on the year of construction (Jacobs et al. 2002). The study area had no industrial sources of lead exposure.

Site 1 was a 40 m \times 50 m block of 26 two-story row houses on a 3.5-m-wide alley street with 12 houses on one side and

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Lead dust-fall findings of this study were presented at a community meeting with study participants and officials from Baltimore City and State of Maryland agencies in November 2001.

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14 houses on the other (Figure 1A). All houses on the block had been renovated in the early 1980s, except for 5 houses on the southwestern portion of the block (Figure 2A). Most houses had dirt backyards that extended approximately 7 m to a narrow (~2 m) back alley surrounding the site (Figure 2B). Seventy-five mostly occupied two- and three-story row houses were located directly across the back alleys surrounding the site and were within approximately 15 m of the site. Demolition of all 26 houses on the block occurred between 27 October and 8 November 1999 (Figure 3A–C).

Site 2 was composed of 27 two-story row houses on a 38 m × 46 m block of a narrow 3.5-m-wide alley street. All 13 houses on the east side of the street and 5 houses on the ends

of the west side of the street were demolished during 19–26 April 2000 ($n = 18$ houses demolished; Figure 1B, Figure 3D–F). Nine houses in the middle of the west side of the street were not demolished. Blocks of two- and three-story row houses were located to the east, west, and south of the site. To the north was a vacant lot created as a result of whole-block demolition performed a year earlier.

Site 3 was composed of partial block demolitions performed during 1–12 April 2000 on a total of 20 row houses on two adjacent blocks located within 100 m west of site 2 (Figure 1C). The two adjacent blocks were located on wider residential streets. One mostly vacant residential block was located to the west of the site.

Demolition methods. Demolition at each site was performed using track-mounted excavator equipment with either a “claw” bucket or a material handler (Figure 3A, C, D). Water was sprayed during demolition using a 3-inch hose at site 1 and a 1-inch hose at sites 2 and 3. Whole-block demolition was typically done during the course of 1 day (Figure 3B). Excavator equipment was used to load demolition debris into roll-off bins or trucks that were placed close to the work site (Figure 3C,D). In some cases, water was sprayed during debris removal (Figure 3D). The roll-off bins were removed from the site by truck.

Debris removal work took 1–2 weeks per site and involved the loading and removal of approximately 15 roll-off bins for each row

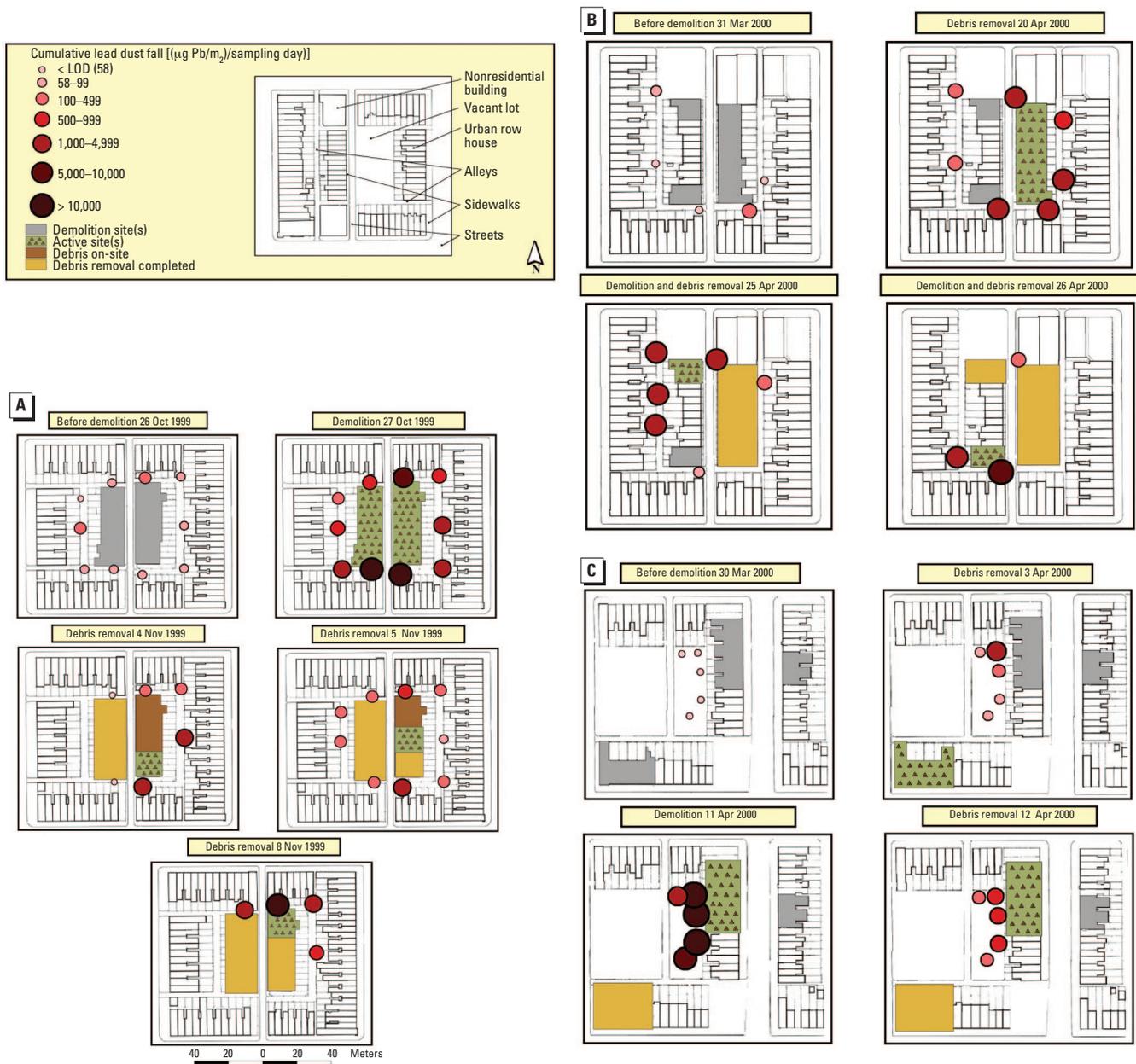


Figure 1. Cumulative lead dust fall by site and phase of demolition: (A) Site 1. (B) Site 2. (C) Site 3. LOD, limit of detection.

house demolished. Each roll-off bin held approximately 15.3 m³ (20 yd³) of debris. At site 1, for example, approximately 400 roll-offs were loaded and removed between 28 October and 8 November 1999. Where only two or three houses were demolished at a time (e.g., the ends of one side of the street at site 2), demolition and debris removal work was completed on the same day. After debris removal at site 1, basements and the entire vacant lot was backfilled with soil with low lead concentration (< 200 mg/kg) from a remote location. Sites 2 and 3 were backfilled with soil or covered with gravel (Figure 3F).

Field data collection. Lead in paint. Testing of lead in paint was performed in a subset of houses at sites 1 and 2 that could be safely accessed before demolition. A certified lead inspection firm performed the testing using a portable X-ray fluorescence (XRF) analyzer. Due to safety concerns, convenience testing was conducted on readily accessible surfaces (painted front and side exterior walls and painted surfaces on the first floors of the houses, including window sills, door trim, walls, baseboards, and ceilings).

Dust fall. Samples were collected from fixed locations at the fence lines of houses directly across the alleys surrounding sites 1 and 2 at baseline, during demolition, and during debris removal (Figure 1A,B). All but one of the sampling locations were within 10 m of the site. On selected sampling days during debris removal at sites 1 and 2, samples were collected from a subset of locations closest to the active work area. At site 3, sampling was performed only at locations close to the active work area during demolition and debris

removal (Figure 1C). Dust fall was collected in a 5.7 L (1.5 gallon) plastic container (depth, 11 cm; diameter, 20 cm; area of opening, 0.0613 m²) containing 0.8 L of deionized water according to American Public Health Association (APHA) Method 502 for dust-fall air sampling (APHA 1977). The container was suspended 1.5 m above the ground (Figure 2B) to prevent tampering. Sampling was usually performed for 4–8 hr on any given day (average time, 6.8 hr) during the period of active work. After sampling, the dust-fall container was sealed for transfer to the laboratory. A total of 101 dust-fall samples and one field blank were collected on 15 sampling days across the three sites; two samples from site 2 were voided in the field. The remaining 99 samples (site 1, *n* = 49; site 2, *n* = 30; site 3, *n* = 20) and the field blank were analyzed for lead.

Because dust fall represents a source of continuing exposure via contaminated surfaces, the dust-fall method was employed in this study as opposed to the more traditional air sampling methods. The dust-fall method yields multiple end points (i.e., dust fall per hour, cumulative lead dust fall per sampling period on any given day, and dust lead concentration) that are comparable with the dust lead loading and dust lead concentration estimates provided by the vacuum-based cyclone device used to collect exterior and interior surface dust in this study.

Sample preparation and laboratory analysis. As specified in APHA Method 502 (APHA 1977), water in the dust-fall collection container was filtered through a #20 mesh screen to remove extraneous material. The water was then filtered through 55 mm glass

microfiber filter paper (particle retention, 0.7 μm) using a membrane filtering system attached to a GAST model MDA-P109-AA vacuum pump (GAST Manufacturing, Inc., Benton Harbor, MI). Before measuring the tared and loaded weight, the filter paper was placed in a drying oven for a minimum of 4 hr. Tared and loaded weights were measured using a Mettler AM100 analytical balance (Mettler-Toledo, Inc., Columbus, OH).

The loaded filter paper was digested using nitric acid hot-plate digestion according to U.S. Environmental Protection Agency (EPA) Method 3050 (U.S. EPA 1986a). The following reagents were used: nitric acid (trace metal grade, concentrated, 69.9–70%; J.T. Baker, Mallinckrodt Baker, Inc., Phillipsburg, NJ), hydrogen peroxide (30% reagent ACS; Mallinckrodt Baker, Inc.), and deionized water. Digestates were analyzed for lead by inductively coupled plasma-atomic emission spectroscopy (Perkin Elmer Plasma 1000; Perkin Elmer, Wellesley, MA) according to U.S. EPA Method 6010 (U.S. EPA 1986b). The following standard solutions were used for calibration: 0.25, 0.5, 1.0, 5.0, 10.0, and 20.0 mg/kg. Standard solutions were prepared in 10% nitric acid from Pure Atomic Spectroscopy Standard (1,000 mg/kg lead; Perkin Elmer).

To test for dissolved lead, the eluent from a subset of 28 of the 99 samples across the three sampling phases (baseline, demolition, and debris removal) was digested using nitric acid hot-plate digestion according to U.S. EPA Method 3050 (U.S. EPA 1986a). All filtrate lead concentrations were below the calculated limit of quantitation (0.35 μg/mL) except for one baseline sample, indicating that dissolution of lead was not a problem.

Quality control samples were prepared using Lead Standard Solution (1,000 mg/kg lead; GFS Chemicals, Inc., Powell, OH). The mean lead recovery on stock solution spikes (*n* = 12) and spike duplicates (*n* = 12) was 94% (range, 84–102%). No evidence of systematic lead contamination was found for method blanks (*n* = 8) or reagent blanks (*n* = 9). Median lead concentrations were below the calculated instrumental detection limit (IDL; 0.071 μg/mL) for reagent blanks and minimally exceeded the IDL for method blanks. The one field blank had a lead concentration below the IDL.

Data analysis. Data analysis included the calculation of the following dust-fall metrics: lead dust-fall rate per hour (micrograms Pb per square meter per hour), cumulative lead dust-fall rate (micrograms Pb per square meter per sampling period on any given day), and lead concentration (milligrams Pb per kilogram of dust). The calculated limit of detection (LOD) was 58 μg Pb/m²/sampling day for cumulative lead dust fall, which is



Figure 2. Before demolition, site 1. (A) Row houses. (B) Dust-fall collection apparatus with arrow pointing to another view of the same sampling location.

equivalent to $8.5 \mu\text{g Pb/m}^2/\text{hr}$ for an average 6.8 hr sampling period. For data analysis purposes, samples with values $< \text{IDL}$ were recorded as IDL divided by the square root of 2 (Hornung and Reed 1990). Three samples at site 2 were excluded because they were distant from the active work area (Table 1). Data analysis was based on 96 field samples. The dust-fall data were transformed using the natural logarithm before data analysis. The regression analysis was performed using generalized estimating equations (GEE) to account for correlation over time. The regression model included phase (baseline, demolition, and debris removal) and sample collection date. The latter was included to control for variability across sampling days that might be due to ambient conditions, including weather. The results are reported to two significant figures.

Geographic information system displays. Maps ($61 \text{ cm} \times 91.4 \text{ cm}$) of the study areas were obtained from the Baltimore City Department of Planning and scanned using a large-format scanner (OCE 9800; OCE-USA Holding, Inc., Chicago, IL) to create electronic images in JPEG files. Adobe Illustrator 9.0 (Adobe Systems, Inc., San Jose, CA) was used to edit the scanned images before data display using Arc View GIS software, version 3.2 (ESR Institute 1996).

Results

Lead in paint. Convenience XRF testing before demolition at sites 1 and 2 revealed the presence of residential lead-based paint. Nine of the 26 (35%) houses demolished at site 1 were tested for lead in paint, including four of the five houses that had not been renovated (Figure 2A). In every unrenovated house tested, the maximum XRF reading was $> 9.9 \text{ mg/cm}^2$, indicating a high amount of lead in the paint. The maximum reading per house in four of the renovated houses was less than Maryland's action level of 0.7 mg/cm^2 . In the fifth renovated house tested, the maximum XRF reading was also $> 9.9 \text{ mg/cm}^2$ on an exposed section of an original wall that had been covered with drywall. At site 2, 5 of the 13 (38%) houses on the side of the street that was completely demolished were tested; all 5 houses had maximum XRF reading $> 6.0 \text{ mg/cm}^2$. Two houses on the other side of the street, which were not slated for demolition, were also tested. One house had a maximum XRF reading $> 8.0 \text{ mg/cm}^2$, and the other had a maximum reading $< 0.7 \text{ mg/cm}^2$.

Dust-fall lead loadings. Table 1 displays descriptive statistics on lead dust-fall rates on an hourly and a cumulative basis by site and by phase. Cumulative lead dust fall for 80 of the 99 individual dust-fall samples are presented in Figure 1A–C by site and by phase. Figure 1A shows baseline data for 10 samples collected on 26 October 1999 [geometric mean (GM), 84

$\mu\text{g Pb/m}^2/\text{sampling day}$] at site 1. Similar baseline results ($\text{GM} < 58 \mu\text{g Pb/m}^2/\text{sampling day}$) obtained from the same 10 locations on 25 October 1999 are not shown in Figure 1A. Figure 1B displays baseline results for five samples collected on 31 March 2000. Similar baseline results for eight samples collected 18 November 1999 (Table 1), and data for one other sample collected 25 April 2000 at a location beyond the map display, are not shown in Figure 1B. Dust-fall data for the demolition phase on the east side of site 2 (Figure 1B) were not collected because of a lack of advance notice of demolition.

Using data pooled across the three sites, the baseline (predemolition) GM lead dust-fall rate was $10 \mu\text{g Pb/m}^2/\text{hr}$ and $62 \mu\text{g Pb/m}^2/\text{sampling day}$ for cumulative lead dust fall. These baseline GM values are slightly above the LOD (Table 1). Nearly half of the individual baseline readings were below the LOD (Figures 1A–C). All lead dust-fall

measurements at baseline were lower than those during demolition. Acute increases in lead in dust fall were detected at all three sites during demolition and to a lesser degree during debris removal (Figures 1A–C). GM lead dust fall increased to $410 \mu\text{g Pb/m}^2/\text{hr}$ on an hourly basis and to $2,700 \mu\text{g Pb/m}^2/\text{sampling day}$ on a cumulative basis during demolition (i.e., an increase of more than 40-fold above baseline). Maximum cumulative lead dust-fall values were $35,000 \mu\text{g Pb/m}^2$ during demolition and $26,000 \mu\text{g Pb/m}^2$ during debris removal. During debris removal, the GM lead dust-fall rate increased to $61 \mu\text{g Pb/m}^2/\text{hr}$ and to $440 \mu\text{g Pb/m}^2$ for cumulative lead dust fall (i.e., a more than 6-fold increase above baseline). The increases during demolition and debris removal were statistically significant for both lead dust fall and cumulative lead dust fall. None of the sample location or site differences were statistically significant in the GEE model in the

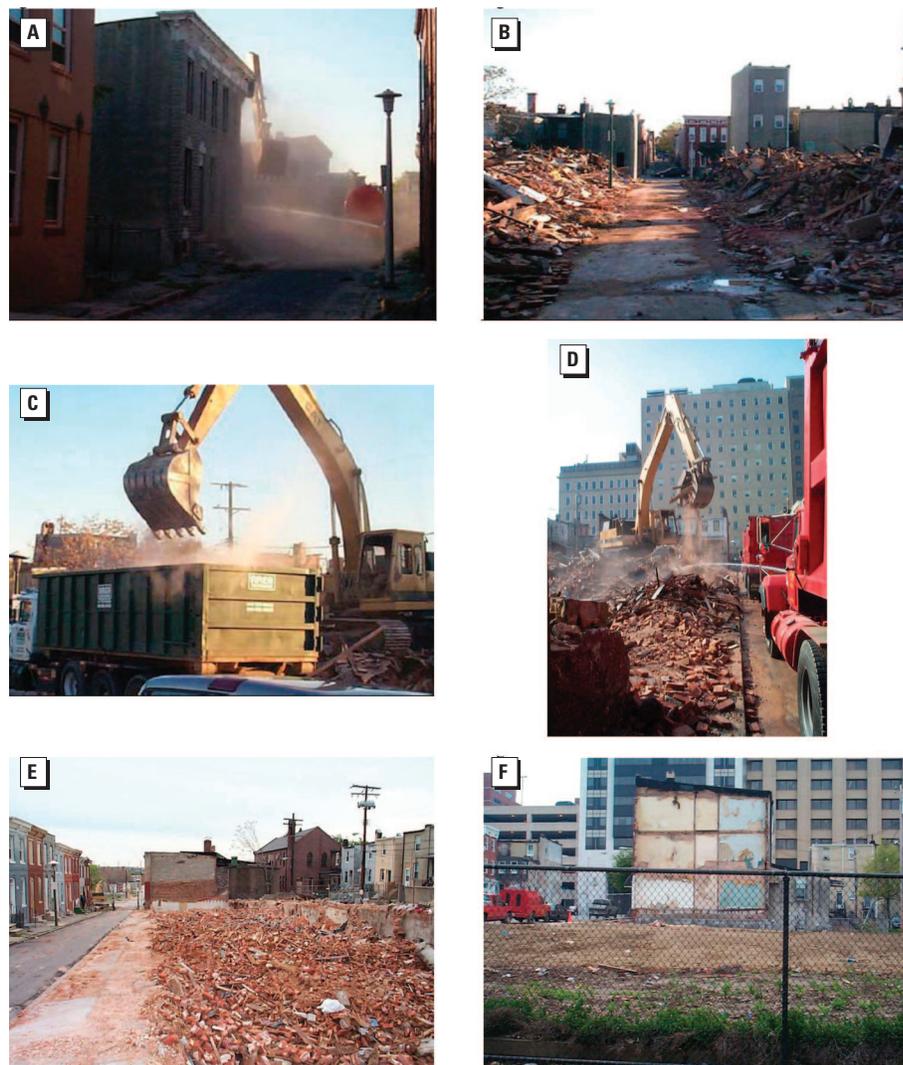


Figure 3. Demolition in progress. Site 1: (A) during demolition; (B) after demolition and before debris removal; and (C) debris removal. Site 2: (D) debris removal; (E) after debris removal; and (F) vacant lot.

presence of demolition phase and sample collection date.

Dust-fall lead concentrations. Fifty-three percent (20 of 38) of the baseline samples and 14% (5 of 36) of the samples collected during debris removal had dust masses < LOD (0.002 g). The low dust masses precluded the calculation of lead concentrations for these 25 samples. Table 2 shows descriptive statistics for dust-fall lead concentrations by site and by phase for the samples with dust masses > LOD. Based on pooled data, GM lead concentrations during demolition (GM, 2,600 mg/kg) and debris removal (GM, 1,500 mg/kg) were higher than the GM lead concentration at baseline (950 mg/kg). The ranges of the lead concentration during demolition (1,200–6,900 mg/kg) and during debris

removal (560–5,100 mg/kg) were higher than the range of values at baseline (340–4,700 mg/kg). The increased dust-fall lead concentration during demolition was statistically significant. The increase in lead concentration during debris removal compared with baseline was of borderline statistical significance. None of the sample location or site differences were statistically significant in the regression model in the presence of phase and sample collection date.

Discussion

In this study we investigated whether demolition of older urban row houses is associated with increased lead levels in ambient dust. It was not intended to be a comprehensive study of factors influencing the patterns and changes in lead in dust. By design, the environmental

sampling was conducted close to the demolition site to maximize the ability to detect changes in ambient lead levels. In the case of dust fall, sampling was conducted at the fence line of the immediately adjacent properties surrounding the demolition sites. The extent to which this contamination is spread beyond the fence line is unknown.

Demolition and debris removal activities were found to be associated with significant and acute increases in lead dust fall within 10 m of the three demolition sites. The increase in lead dust-fall rate above baseline levels was greater during demolition (~40-fold) than during debris removal (~6-fold) (Table 1 and photographs of visible dust emissions in Figure 3A, C, D). Some lead dust-fall rates during debris removal, however, were just as high as those during demolition (e.g., Figure 1A). Lead dust fall tended to be the highest at sampling locations closest to the active work areas (e.g., Figure 1A, 4 and 8 November 1999) and at downwind sampling locations as noted on particular sampling days (e.g., Figure 1A, 27 October and 5 November 1999; wind direction, south). It should be noted that these findings were associated with site wetting of limited effectiveness during demolition (Figure 3A) and with limited or no wetting during debris removal (Figure 3C, D). Our findings are consistent with those of Diorio (1999) and emphasize the need for more effective dust suppression during demolition and debris removal.

The dust-fall loading results indicate that lead was deposited at a higher rate during demolition than during debris removal. The increase in dust-fall lead concentration above baseline was also greater during demolition (2.7-fold increase) than during debris removal (1.6-fold increase). These findings likely reflect a greater degree of disruption of lead-based paint present on interior and exterior surfaces of the demolished houses and subsequent higher rate of dispersion of lead paint particles and lead-containing dust during demolition compared with debris removal. Other likely sources of lead in dust fall during demolition are lead-containing dusts present on interior and exterior surfaces of the demolished houses, and settled street and sidewalk dust that might have become airborne as a result of demolition activities. The apparent greater degree of disruption of paint and dust during demolition is related to the fact that demolition tends to disturb a larger mass of material at a greater height and generates more air movement at any given time compared with debris removal activities.

Debris removal activities disturb and disperse lead dust contained in the debris pile. In fact, the debris removal process can potentially disperse a greater mass of lead in dust fall than does demolition because the former involves an

Table 1. Descriptive statistics for cumulative lead dust fall ($\mu\text{g}/\text{m}^2/\text{per sampling day}$) and hourly lead dust fall ($\mu\text{g}/\text{m}^2/\text{hr}$) by site and phase of demolition.

Site	Phase	No.	Cumulative lead dust fall				Hourly lead dust fall			
			GM	GSD	Min	Max	GM	GSD	Min	Max
All	Baseline	38	62	1.6	< 58 ^a	220	10	1.6	< 8.5 ^b	29
	Demolition	22	2,700	4.4	250	35,000	410	4.5	34	6,400
	Debris removal	36	440	4.5	< 58	26,000	61	4.4	< 8.5	3,300
1	Baseline	20 ^c	67	1.6	< 58	220	10	1.6	< 8.5	29
	Demolition	10	2,200	4.5	340	29,000	230	4.5	34	3,000
	Debris removal	19	460	5.4	< 58	26,000	58	5.3	< 8.5	3,300
2	Baseline	8 ^d	73	1.5	< 58	120	12	1.7	< 8.5	22
	Baseline	5 ^e	< 58	1.6	< 58	100	9	1.7	< 8.5	18
	Demolition	7 ^f	1,500	2.9	250	9,200	350	2.6	69	1,600
	Debris removal	7	940	2.9	220	3,700	140	2.9	33	580
3	Baseline	5	< 58	— ^g	< 58	< 58	< 8.5	1.3	< 8.5	10
	Demolition	5	9,100	4.0	1,100	35,000	1,600	4.0	200	6,400
	Debris removal	10	230	3.1	64	1,500	37	3.2	10	220

Abbreviations: GSD, geometric standard deviation; Max, maximum; Min, minimum.

^aLOD for cumulative lead dust fall is 58 $\mu\text{g}/\text{m}^2$ per sampling day. ^bLOD for hourly lead dust fall is 8.5 $\mu\text{g}/\text{m}^2/\text{hr}$. ^cSamples were collected from the same sampling locations on 25 and 26 October 1999. ^dEight samples were collected on 18 November 1999. ^eFive samples were collected on 31 March 2000. ^fSamples collected at site 2 reflect both demolition and debris removal activities done during the same day on a subset of houses on 25 and 26 April 2000. Three samples collected from locations more distant from the active work area were excluded from the data analysis: two samples from 25 April (lead dust fall = 15 $\mu\text{g}/\text{m}^2/\text{hr}$, cumulative lead dust fall < LOD; and lead dust fall = 23 $\mu\text{g}/\text{m}^2/\text{hr}$, cumulative dust fall = 85 $\mu\text{g}/\text{m}^2/\text{per sampling day}$) and one sample from 26 April (lead dust fall = 38 $\mu\text{g}/\text{m}^2/\text{hr}$, cumulative lead dust fall = 200 $\mu\text{g}/\text{m}^2/\text{per sampling day}$). The first excluded sample from 25 April was too distant from the site to be displayed in Figure 1B. ^gThe GSD was zero because all five values were < IDL.

Table 2. Descriptive statistics for dust fall lead concentrations (mg/kg) by site and phase of demolition.

Site	Phase	No.	GM	GSD	Min	Max
ALL	Baseline	18	950	2.0	340	4,700
	Demolition	22	2,600	1.5	1,200	6,900
	Debris removal	31	1,500	1.8	560	5,100
1	Baseline	8 ^a	1,100	2.4	390	4,700
	Demolition	10	3,100	1.6	1,200	6,900
	Debris removal	16 ^b	1,300	1.7	560	3,800
2	Baseline	2 ^c	1,500	1.7	1,100	2,100
	Baseline	5 ^d	710	1.9	340	1,300
	Demolition	7 ^e	2,700	1.3	1,900	3,700
	Debris removal	7	3,000	1.4	2,000	5,100
3	Baseline	3 ^f	840	1.6	490	1,100
	Demolition	5	1,800	1.3	1,500	2,700
	Debris removal	8 ^g	1,300	1.7	800	4,400

Abbreviations: GSD, geometric standard deviation; Max, maximum; Min, minimum.

^aExcludes 12 samples with mass < LOD. ^bExcludes 3 samples with mass < LOD. ^cExcludes 6 samples with mass < LOD out of a total of 8 samples collected on 18 November 1999. ^dFive samples were collected on 31 March 2000. ^eSamples collected at site 2 reflect both demolition and debris removal activities done during the same day on a subset of houses on 25 and 26 April 2000. Three samples collected from locations more distant from the active demolition site were excluded from the data analysis: two samples from 25 April (lead concentration = 820 mg/kg and 1,100 mg/kg) and one sample from 26 April (lead concentration = 1,100 mg/kg). The first excluded sample from 25 April was too distant from the site to be displayed in Figure 1B. ^fExcludes 2 samples with mass < LOD. ^gExcludes 2 samples with mass < LOD.

extended process of loading and hauling away a large volume of debris. In this study, debris removal entailed the loading of hundreds of roll-off bins over a period of 1–2 weeks. Based on our findings (Table 1), we estimated that the 1-day demolition was associated with a mean total lead dust fall of 2,700 $\mu\text{g Pb}/\text{m}^2$ in the zone within 10 m of the demolition site (calculated as 2,700 $\mu\text{g}/\text{m}^2/\text{day} \times 1$ day of activity), whereas the debris removal was associated with an estimated total of 4,400 $\mu\text{g Pb}/\text{m}^2$ (calculated as 440 $\mu\text{g}/\text{m}^2/\text{day} \times 10$ days of activity in which one excavator was operational per day). Additionally, transportation of the loaded roll-off bins with debris away from the site can potentially disperse dust lead into the ambient environment beyond the immediate vicinity of the demolition site.

The relatively high lead concentration of dust fall at baseline (GM, 950 mg/kg) likely reflects the fact that study sites were located in older urban neighborhoods (median year of construction, 1939–1946) with residential lead paint and lead-contaminated exterior dusts and soils. In fact, in this study, preliminary data on the baseline concentrations of lead in street dust (GM, ~700 mg/kg), sidewalk dust (GM, ~2,000 mg/kg), and residential entryway mat dust (GM, ~750 mg/kg) collected within 100 m of the study sites were similar to the GM dust-fall lead concentration at baseline. In another study, similar lead concentrations (range, 300–2,000 mg/kg) were measured in yard soil in these and other inner city neighborhoods of Baltimore (Orlova et al. 2001). The similarity of dust-fall lead concentrations at baseline and during demolition and debris removal suggests that they share common source(s) of lead (e.g., lead-based paint) and that past demolition-related dust deposition might be one pathway to lead in dust fall measured at baseline. Other pathways might be deterioration of exterior lead paint and historic deposition of gasoline lead additives.

The similarity of findings across the three study sites suggests that the findings are likely to be generalizable to other neighborhoods in Baltimore where older row homes are demolished using the same practices. Also regarding generalizability, it is important to note that no differences were found between the demolition of blocks of older unrenovated houses (sites 2 and 3) and the demolition of a block of older mostly renovated houses (site 1) in which windows and doors had been replaced and walls had been covered but some interior and exterior lead painted surfaces remained (e.g., behind drywall). To the degree that similar demolition practices are used elsewhere, the findings would be widely generalizable because row houses comprise the predominant type of housing in inner city neighborhoods in Baltimore and other cities.

Public health significance. The substantial acute increase in lead in dust fall during demolition and debris removal activities compared with baseline suggests that demolition activities can increase the risk of lead exposure to neighborhood residents and workers. We observed, and residents anecdotally reported, a lack of control of public access to the sites (Figure 3A–E). Children and adults were seen walking through the site and on the debris pile during and immediately after the active work phase. Residents also reported that windows of neighboring houses were left open and that laundry and pets remained outside during demolition work. These situations likely reflect the reported absence of advance notification and health education to community residents about measures to protect themselves from demolition dust fall and other potential health and safety hazards.

Dust fall represents a residual (and additive) source of lead dust in the urban environment. Lead in dust fall dispersed during demolition and debris removal can increase the risk of lead exposure beyond the acute work phase, especially for young children, by increasing lead loadings of settled ambient dust. Lead-contaminated settled ambient dust is also of concern because it can be tracked into houses on shoes or blown into houses (Adgate et al. 1998; Bornschein et al. 1986). This is important because for young children the time spent indoors is typically greater than the time spent outdoors (U.S. EPA 1997b), and therefore the likelihood and frequency of exposure to lead in dust are expected to be greater for interior surfaces than for exterior surfaces.

Currently, there are no health-based standards for lead dust fall. HUD had a postabatement clearance guidance level, based on wipe sampling, of 800 $\mu\text{g}/\text{ft}^2$ (equivalent to 8,620 $\mu\text{g}/\text{m}^2$) for exterior concrete or other rough surfaces (HUD 1995) that was not included in the U.S. EPA's recent lead loading standards for dust on residential surfaces (U.S. EPA 2001). To better understand the public health significance of the findings, the results were compared with the U.S. EPA standard for lead in settled dust on residential floors (40 $\mu\text{g}/\text{ft}^2$, equivalent to 431 $\mu\text{g}/\text{m}^2$; U.S. EPA 2001). The rationale for this comparison is that dust fall settles on exterior surfaces and, in turn, becomes a pathway of lead exposure in young children, via the hand-to-mouth route of ingestion, in and around the homes in the community surrounding the demolition site.

The contribution of demolition dust fall to settled ambient dust is of public health concern because our findings show that lead in demolition dust fall can substantially exceed the equivalent U.S. EPA standard for residential floor lead loadings. During demolition, the GM value for cumulative lead in dust fall (2,700 $\mu\text{g}/\text{m}^2$ per sampling day) was 6.3 times

greater than the U.S. EPA's residential floor-dust lead standard. During debris removal, the GM cumulative lead dust fall (440 $\mu\text{g}/\text{m}^2$ per sampling day) was just above the U.S. EPA's residential floor-dust lead standard. The maximum cumulative lead dust-fall values during demolition (35,000 $\mu\text{g}/\text{m}^2$ per sampling day) and debris removal (26,000 $\mu\text{g}/\text{m}^2$ per sampling day) exceeded the U.S. EPA's residential floor dust lead standard by 81-fold and 60-fold, respectively. Before demolition, all of the dust-fall results, cumulative dust-fall results, and GM values for these end points were well below the equivalent U.S. EPA standard for lead in settled dust on residential floors.

The public health concern regarding the increased risk of lead exposure associated with residential demolition is particularly important in older urban communities undergoing urban redevelopment that involves the demolition of multiple blocks of houses. Such communities, already at high risk of lead poisoning because of poor housing conditions and age of housing (President's Task Force 2000), have likely experienced cumulative increases in ambient lead from multiple demolitions in the same neighborhood over time. In fact, this study was conducted in a federal empowerment zone with a history of whole-block demolitions and where plans are pending for large-scale demolitions of row houses in the near future. The part of the empowerment-zone community slated for future demolition has a low-income minority population and young children at high risk of lead poisoning. In 1997, for example, approximately 60% of tested children 12–36 months of age in this area had blood lead concentrations above 10 $\mu\text{g}/\text{dL}$ (Maryland Department of the Environment 2000).

Conclusion

The literature on abatement, repair, and renovation of houses containing lead-based paint shows that certain methods and activities (e.g., paint removal by sanding, dry scraping, and use of open flame torches, and interior demolition) can generate large quantities of lead-containing dust and that proper methods and practices need to be implemented to control and contain dust lead hazards (HUD 1995; U.S. EPA 1997c). Our study shows that this is also true when houses containing lead paint are demolished.

For this reason, demolition needs to be conducted in a manner that minimizes lead exposure for residents, workers, and the environment so that the process of redevelopment does not exacerbate existing risks of lead poisoning. In particular, the dust-fall results presented here highlight the need to identify and implement improved work practices to minimize the dispersion of lead during demolition and debris removal and to limit public access to the demolition site. The approaches,

precautions, methods, and safe work practices described in *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (HUD 1995), including practices to minimize and contain lead dust and to otherwise protect occupants and workers, can help inform the development of a new protective approach to urban residential demolition.

Additional studies are needed to investigate lead dispersion and nonlead end points associated with demolition of various types of residential structures and with other types of demolition practices, including improved practices to control fugitive dust emissions. Future research is needed to assess changes in lead dust fall at distances > 10 m from the demolition site, to assess longer-term changes in lead dust fall postdemolition, characterize the lead in dust fall (e.g., particle size), and assess the need for longer sampling times to account for settling of finer particles, if any, that may not have been captured within our sampling period. It is also important to understand the influence of the type, height, and configuration of the surrounding houses, and meteorologic conditions, on lead dispersal.

Another critical element in addressing public health issues associated with demolition is the development of mechanisms to provide residents living in the vicinity of the demolition site with advance notification of demolition and information on steps they can take to minimize their risk of associated lead exposure. During the course of this study, community residents anecdotally expressed concerns about the demolition process that relate to their safety and other environmental health hazards, such as rats, waste water, noise, and dust allergens, and the lack of street and sidewalk cleaning after demolition. These concerns warrant further investigation and should be taken into account as needed in the process of planning and implementing demolition. This study also suggests that control of lead exposure among demolition workers warrants further attention.

Understanding, recognizing, and addressing lead and other housing-related environmental health issues associated with demolition, and related community concerns, will help society attain the full public health benefits of demolition and urban redevelopment. Unfortunately, urban planners, developers, and contractors may not be well informed of the lead risks associated with the demolition of older housing. In the context of residential remodeling

and renovation work in pre-1978 housing, EPA's Pre-Renovation Education Rule (U.S. EPA 2002) requires contractors to supply the owner and occupant with an information pamphlet on lead hazards before starting the renovation, except for very small projects. [The rule implements section 406(b) of the Toxic Substances Control Act (U.S. EPA 1976); the section was created by the Residential Lead-Based Paint Hazard Reduction Act of 1992, known as Title X (Alliance to End Childhood Lead Poisoning 1993)]. No such federal requirement exists for residential demolition.

Some local communities are taking actions to address this issue. The city of Wausau, Wisconsin, is providing applicants for demolition permits with an educational pamphlet on how to control demolition dust (Wasson 2002). In Baltimore, educational materials about potential demolition hazards and protective measures have been developed for distribution to residents living near demolition sites, and community residents have been trained as outreach educators for urban demolition. These efforts are part of a collaborative effort by the authors, community organizations, and local and state agencies to develop a preventative approach to urban residential demolition that addresses community concerns about current demolition practices. It is particularly important that urban redevelopment and public health agencies become more aware of demolition-related public health issues in light of the large numbers of older lead-painted houses that are estimated to be demolished nationwide in future years (President's Task Force 2000).

REFERENCES

- Adgate JL, Rhoads GG, Lioy PJ. 1998. The use of isotope ratios to apportion sources of lead in Jersey City, NJ, house dust wipe samples. *Sci Total Environ* 221:171–180.
- Alliance to End Childhood Lead Poisoning. 1993. Understanding Title X: A Practical Guide to the Residential Lead-Based Paint Hazard Reduction Act of 1992. Available: http://www.hud.gov/offices/lead/regs/u_titlex.pdf [cited 4 June 2003].
- APHA. 1977. Method 502: Tentative Method of Analysis for Dustfall from the Atmosphere. In: *Methods of Air Sampling and Analysis*. (Katz M, ed). 2nd ed. Washington DC: American Public Health Association, 585–587.
- Bareford PE, Record FA. 1982. Air Monitoring at the Bourne Bridge Cape Cod Canal, Massachusetts, 30 Oct 1979 through 31 May 1981: Final Report. NTIS no. AD-A1200500. Bedford, Mass: GCA/Technology Division.
- Bornschein RL, Succop PA, Krafft KM, Clark CS, Pease B, Hammond PB. 1986. Exterior surface dust lead, interior house dust lead and childhood lead exposure in an urban environment. In: *Trace Substances in Environmental Health* (Hemphill DD, ed), XX, Proceedings of the University of Missouri's 20th Annual Conference, June 1986, Columbia, MO. Columbia, MO: University of Missouri, 322–332.
- CDC. 2000. Blood lead levels in young children—United States and selected states, 1996–1999. *Morbidity and Mortality Weekly Report* 49(50):1133–1137.
- Diorio JJ. 1999. Fugitive lead dust from the demolition of residential housing. *Environ Health Update*, January/February:36–37.
- Hornung RW, Reed LD. 1990. Estimation of average concentration in the presence of nondetectable values. *Appl Occup Environ Hygiene* 5:46–51.
- ESR Institute. 1996. Using ArcView GIS. Redlands, CA: Environmental System Research Institute, Inc.
- HUD. 1995. Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing. Washington, DC: U.S. Department of Housing and Urban Development.
- Jacobs DE, Friedman W, Clickner RP, Zhou JY, Viet SM, Marker DA, et al. 2002. The prevalence of lead-based paint hazards in U.S. housing. *Environ Health Perspect* 110:A599–A606.
- Landrigan PJ, Baker EL Jr, Himmelstein JS, Stein GF, Weddig JP, Straub WE. 1982. Exposure to lead from the Mystic River Bridge: the dilemma of deleading. *N Engl J Med* 306:673–676.
- Maryland Department of the Environment. 2000. Childhood Lead Registry. Percent of Children 0–72 Months Screened for Lead Poisoning with Blood Lead Levels ≥ 10 $\mu\text{g}/\text{dL}$: Baltimore City Census Tracts (1992–1997 data). Baltimore, MD: Maryland Department of the Environment.
- Orlova AO, Farfel MR, Lees PSJ, Chaney R, Ashley PJ. 2001. Biosolid application for reducing urban soil lead hazards: baseline results. In: *Proceedings of the 6th International Conference on the Biogeochemistry of Trace Elements*, 29 July–2 August 2001, Guelph, Ontario, Canada. Guelph: University of Guelph, 235.
- President's Task Force on Environmental Health Risks and Safety Risks to Children. 2000. Eliminating Childhood Lead Poisoning: A Federal Strategy Targeting Lead Paint Hazards. Available: <http://www.epa.gov/opptintr/lead/fed-strategy2000.pdf> [accessed 23 May 2003].
- U.S. EPA. 1976. Toxic Substances Control Act, Title 15, Chapter 53, Subchapter IV Lead Exposure Reduction, Section 2686. Lead Hazard Information Pamphlet. Available: <http://www4.law.cornell.edu/uscode/15/2686.html> [accessed 30 May 2002].
- . 1986a. Test Methods for the Evaluation of Solid Waste: Laboratory Manual Physical Chemical Methods: Method 3050: Acid Digestion of Sediments, Sludges and Soil. Vol 1A. Washington, DC: U.S. Environmental Protection Agency.
- . 1986b. Test Methods for the Evaluation of Solid Waste: Laboratory Manual Physical Chemical Methods: Method 6010: Inductively Coupled Plasma Emission Spectroscopy. Vol 2A. Washington DC: U.S. Environmental Protection Agency.
- . 1997a. Lead-Based Paint Abatement and Repair and Maintenance Study in Baltimore: Findings Based on Two Years of Follow-up. EPA 747-R-97-005. Washington, DC: U.S. Environmental Protection Agency.
- . 1997b. Exposure Factors Handbook. Volume III. Activity Factors. EPA/600/P-95/002F. Washington, DC: Office of Research and Development.
- . 1997c. Lead Exposure Associated with Renovation and Remodeling Activities: Summary Report. EPA 747-R-96-005. Washington, DC: U.S. Environmental Protection Agency.
- . 2001. Lead; Identification of Dangerous Levels of Lead; Final Rule. 40CFR745. Fed Reg 66:6763–6765.
- . 2002. Pre-Renovation Notification: State and Tribal Program Requirements. 40CFR745.326.
- Wasson RJ. 2002. City to begin random lead checks. Education, enforcement efforts aimed at demolition permit holders. *Wausau Daily Herald* (Wausau, WI), 11 April. Available: <http://www.wausaudailyherald.com/wdhlocal/277195359047233.shtml> [accessed 15 May 2002].