Lead and Other Heavy Metals in Dust Fall from Single-Family Housing Demolition

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ABSTRACT

Objective. We measured lead and other heavy metals in dust during older housing demolition and effectiveness of dust suppression.

Methods. We used American Public Housing Association Method 502 and U.S. Environmental Protection Agency Methods SW3050B and SW6020 at 97 single-family housing demolition events with intermittent (or no) use of water to suppress dust at perimeter, non-perimeter, and locations without demolition, with nested mixed modeling and tobit modeling with left censoring.

Results. The geometric mean (GM) lead dust fall during demolition was 6.01 micrograms of lead per square foot per hour (µg Pb/ft^2/hour). GM lead dust fall was 14.18 µg Pb/ft^2/hour without dust suppression, but declined to 5.48 µg Pb/ft^2/hour ($p=0.057$) when buildings and debris were wetted. Significant predictors included distance, wind direction, and main street location. At 400 feet, lead dust fall was not significantly different from background. GM lead concentration at demolition (2,406 parts per million [ppm]) was significantly greater than background (GM=579 ppm, $p=0.05$). Arsenic, chromium, copper, iron, and manganese demolition dust fall was significantly higher than background ($p<0.001$). Demolition of approximately 400 old housing units elsewhere with more dust suppression was only 0.25 µg Pb/ft^2/hour.

Conclusions. Lead dust suppression is feasible and important in single-family housing demolition where distances between houses are smaller and community exposures are higher. Neighbor notification should be expanded to at least 400 feet away from single-family housing demolition, not just adjacent properties. Further research is needed on effects of distance, potential water contamination, occupational exposures, and water application.

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Large sources of lead exposure remain, despite considerable progress in reducing exposures in the United States during the past few decades. Thirty eight million housing units in the U.S. have lead-based paint; of those, 24 million have lead-based paint hazards in the form of deteriorated lead-based paint, contaminated dust, and contaminated bare soil, with 37 billion square feet (ft^2) of building components coated with lead paint.[1] Demolition can be expected to disturb lead paint and produce significant emissions of lead dust and other contaminants.[2–6] Dust from only 1 ft^2 of surface painted with lead-based paint in a 100 ft^2 room can result in a potential dust lead loading of 9,300 micrograms per square foot (µg/ft^2), well above the U.S. Environmental Protection Agency (EPA) limit of 40 µg/ft^2 for interior floors. Earlier research has focused mostly on large numbers of multifamily housing units undergoing demolition within a confined geographic area.[1–4] Only one small pilot study[6] has examined single-family housing demolition, which often occurs at scattered sites adjacent to occupied homes, and no studies have reported on metals other than lead in demolition dust.

Population blood lead levels (BLLs) in the U.S. have declined by 84% since the late 1980s,[7] but mean BLLs still remain two orders of magnitude above the natural background BLL,[8] suggesting that large lead exposure sources still remain. Exposure to lead can occur from many pathways and sources, but housing is the main pathway of exposure in the U.S., accounting for approximately 70% of childhood lead poisoning cases.[9]

Furthermore, demolition of older housing in the U.S. has been shown to explain approximately 30% of the variation in children's BLLs during a 20-year time period[10] because, in the long run, lead-contaminated housing is removed from service. But demolition can also contribute to increased exposures in the near term due to lead-contaminated dust. Furthermore, dust emissions from housing demolition have been found to contribute to adverse health effects other than lead poisoning, such as asthma exacerbation.[4]

While lead exposure limits have been developed for paint, interior settled dust, and bare soil,[11] as well as ambient air and drinking water, no standard has been developed for exterior settled dust. The U.S. Department of Housing and Urban Development (HUD) created a cleanup guideline of 800 µg/ft^2 for exterior concrete or other rough surfaces;[12] however, there are no enforceable standards for lead dust hazard identification on exterior surfaces or lead dust fall, and no standards have been incorporated into the U.S. federal regulatory standards. There are also no consistent lead dust-suppression methods in the housing demolition field, although one recent protocol has been developed.[13]

This study is the first to characterize lead and other heavy metals in dust fall from single-family housing demolition.

METHODS

We collected dust fall samples at perimeter and non-perimeter residential property locations near 97 scattered, single-family demolition events (i.e., an event was considered one workday at one location). Older housing units likely to contain lead-based paint and scheduled for demolition were selected as a convenience sample with the aid of local officials and/or developers. To measure dust fall not associated with demolition, we collected street-level background samples at locations farther than one-quarter mile away from the demolition site during the same time interval as demolition and also at 35 non-demolition events (Photo 1). Demolition samples were collected for a median of 4.5 hours each day (range: 2–8 hours).

Lead, other heavy metals, and total dust fall and concentration were measured by American Public Health Association (APHA) Method 502 and EPA Methods SW3050B and SW6020, as modified by Farfel et al.[2] This passive method uses a polyethylene container with a surface area opening of 0.0594 square meters containing 1 liter of deionized water opened to the atmosphere for a measured time period (Photo 2). Particulate matter settles onto and is captured by the water. After sampling, the container was sealed and transported to a laboratory, where the water was filtered; the filter was then dried to a constant weight and analyzed for total dust, lead, and other heavy metal mass by inductively coupled plasma mass spectrometry, with results

Photo 1. Typical locations of perimeter and non-perimeter samples

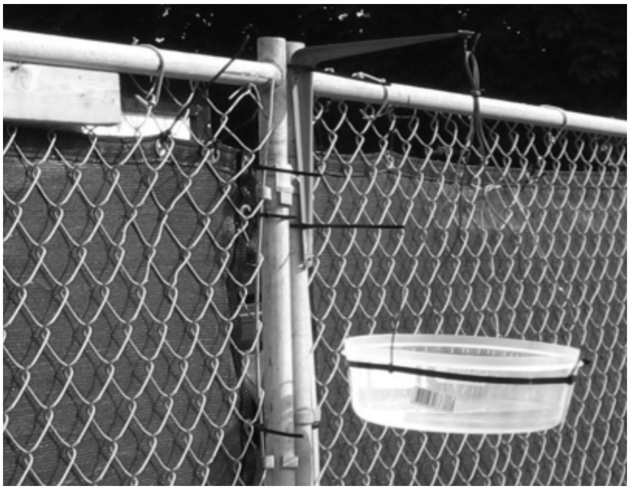


Photo 2. Dust fall sampler apparatus. Source: University of Illinois at Chicago

reported in mass of total dust, lead, and other heavy metals per unit surface area per unit time (μg/ft^2/hour). We chose μg/ft^2 to facilitate a comparison with federal housing standards. If the total dust mass was less than the reporting limit (RL) of 100 μg, a value of 100 μg was used for statistical analysis. RLs for each metal were as follows: arsenic (1 μg), cadmium (4 μg), chromium (4 μg), copper (2.5 μg), iron (100 μg), lead (1 μg), manganese (2 μg), nickel (30 μg), selenium (1 μg), silver (1 μg), and thallium (5 μg). Lead dust fall samples below the laboratory RL were replaced by the RL divided by the square root of two. The analytical laboratory is recognized by the EPA National Lead Laboratory Accreditation Program.

We used a nested mixed model on natural log-transformed dust fall lead loadings that accounted for the correlation of lead dust fall measurements at the same address or on the same day to identify predictors of lead dust fall. We used a backward elimination procedure to eliminate non-significant covariates ($p>0.1$). The model allowed residual variance to differ for the three dust fall sample types (i.e., property perimeter at demolition site, non-perimeter at demolition site, and street-level background at demolition site).

We estimated wind speed using data from a local airport. Sample collection containers were placed in unobstructed locations, with the exact position recorded by global positioning system sensors. We measured traffic density of sample locations by classifying adjacent streets as either side or main streets. We collected field blank samples as a quality control step. We recorded descriptive data on the following variables: ground saturated (yes/no), relative humidity, temperature, atmospheric pressure, wind speed, wind direction, use of a hose, presence of a fence, type of demolition activity (e.g., building razing, debris removal, or both), type of building material (e.g., siding, unpainted/painted wood, or unpainted/painted stone), type of street (main or side), and demolition equipment used (e.g., bulldozer, wrecking ball, picker, or other). We categorized samples into one of three groups according to the amount of time they were located downwind during the sampling events: (*1*) downwind of demolition <5% of the sampling period (55%), (*2*) downwind 5%–50% of the sampling period (20%), and (*3*) downwind >50% of the sampling period (25%).

We recorded data on the use of water for dust suppression, which was either nonexistent (Photo 3) or intermittent (Photo 4). We also used the following variables in modeling: ground saturation (yes/no), average relative humidity, temperature, wind speed and wind direction (downwind <5% of the time, downwind 5%–50% of the time, or downwind >50% of the time) during sampling, the use of a hose to wet down the building and debris (yes/no), presence of a fence (yes/no/unknown), building razing (yes/no) and debris removal (yes/no), primary exterior

Photo 3. No dust suppression used at a demolition site in Chicago. Source: University of Illinois at Chicago

Photo 4. Limited dust suppression in use at a Chicago demolition site. Source: University of Illinois at Chicago

[painted (yes/no), brick/stone (yes/no)] and secondary exterior [painted (yes/no), brick/stone (yes/no)], number of stories, number of dwellings, partly commercial structure (yes/no) and garage (yes/no), whether the sample was on a main street or a side street, and distance from the demolition activity. The model included quadratic and cubic terms to control for wind speed and wind direction.

We analyzed non-lead metals using Tobit models for left-censored measurements under the assumption of log normality for both concentration (in parts per million [ppm]) and dust fall (μg/ft^2/hour), so no substitutions of values below the RL were needed.[14] All data were analyzed using SAS® version 9.1.[15]

RESULTS

The dataset included 463 samples from 97 demolition events and 64 samples from 35 background non-demolition events (Table 1). About 9.6% of the lead dust fall samples were below the RL. The overall GM lead dust fall during demolition was 6.01 μg Pb/ft^2/hour (GSD=4.47). The GM was higher when a water hose was not used to control the dust (n=13 events, GM=14.18 μg Pb/ft^2/hour) than when a water hose was used to control the dust (n=84 events, GM=5.48 μg Pb/ft^2/hour; p=0.057). The GM lead concentrations at demolition site perimeters and non-perimeters were 2,800 ppm and 1,900 ppm, respectively, and were much higher than street-level background (GM=300–1,300 ppm) (Table 1).

Not surprisingly, the effect of distance from demolition on dust fall was modified by wind direction (Table 2). Lead dust fall was lower for samples that were <5% downwind compared with 5%–50% downwind at a distance of 10–240 feet (all $p<0.05$) and marginally lower at a distance of 260–280 feet (p=0.065 and p=0.089 at 260 and 280 feet, respectively). Lead dust

Table 1. Geometric mean total and lead dust fall and concentration measurements at single-family housing demolition and non-demolition locations in Chicago, 2008–2009

Dust fall and lead concentration	*Demolition perimeter (87 events, 261 samples)*	*Demolition non-perimeter (75 events, 158 samples)*	*Street-level background demolition >1/4 mile distance (43 events, 44 samples)*	*Street-level background non-demolition (16 events, 28 samples)*	*Rooftop background non-demolition (19 events, 36 samples)*
Total dust fall (μg/ft^2/hour)	2,202	1,208	589	129	247
Lead dust fall (μg/ft^2/hour)	6.01 (no water hose: 14.18, n=13; hose: 5.48, n=84)[a]	2.45	0.32	0.19	0.09
Lead concentration (ppm)	2,800	1,900	600	1,500	300

[a] "No water hose" means there was no observed wetting of the building and debris before or during demolition; "hose" means that there was some wetting before or during demolition.

μg/ft^2 = micrograms per square foot

ppm = parts per million

Table 2. Parameter estimates of natural logarithm of lead dust fall (μg/ft^2/hour) at single-family housing demolition in Chicago, 2008–2009

Effect	*Estimate (SE)*	P*-value for estimate*	P*-value for effect*
Intercept	3.2072 (0.6031)	<0.001	<0.001
Downwind			<0.001
<5%	–1.1941 (0.3376)	<0.001	
5%–50%	–0.3418 (0.4238)	0.420	
<50%	0	NA	
Distance			<0.001
Downwind <5%	–0.00581 (0.000765)	<0.001	
Downwind 5%–50%	–0.00636 (0.002496)	0.011	
Downwind >50%	–0.00978 (0.003210)	0.002	
Distance^2			<0.001
Downwind <5%	2.967×10^{-6} (0)	<0.001	
Downwind 5%–50%	2.061×10^{-6} (2.601×10^{-6})	0.429	
Downwind >50%	5.51×10^{-6} (4.021×10^{-6})	0.171	
Relative humidity	–0.01845 (0.009939)	0.064	0.064
Type of street			0.079
Side	0.3983 (0.2262)	0.079	
Main	0	NA	

μg/ft^2 = micrograms per square foot

SE = standard error

NA = not applicable

fall was lower for samples that were <5% downwind compared with >50% downwind at a distance of 10–170 feet (all $p<0.05$) and marginally lower at a distance of 180–190 feet ($p=0.063$ and $p=0.093$ at 180 and 190 feet, respectively). Lead dust fall was not different for 5%–50% downwind compared with >50% downwind across the range of distances (10–750 feet). At 400 feet from demolition, the effect of wind was minimal and lead dust fall was not significantly different from background street-level lead dust fall, which has important implications for notification of nearby residents. A convenience sample of community residents showed that dust exposures from demolition, inadequate notice, and dilapidated housing targeted for demolition were all important community concerns (Unpublished report, Bartlett J. Results of interviews with community residents on demolition. Chicago: Metropolitan Tenants Organization; 2009).

While there is no federal regulation governing lead dust fall from demolition, there are two relevant comparison values. In 1995, HUD published a guidance value of 800 μg/ft^2 for settled lead dust on exterior concrete surfaces,[12] and in 2001, EPA published a regulation[11] for interior floor settled lead dust of 40 μg/ft^2. After eight hours of demolition at 400 feet from demolition, the probability of exceeding 40 and 800 μg/ft^2 was 13% and 6%, respectively (Figure).

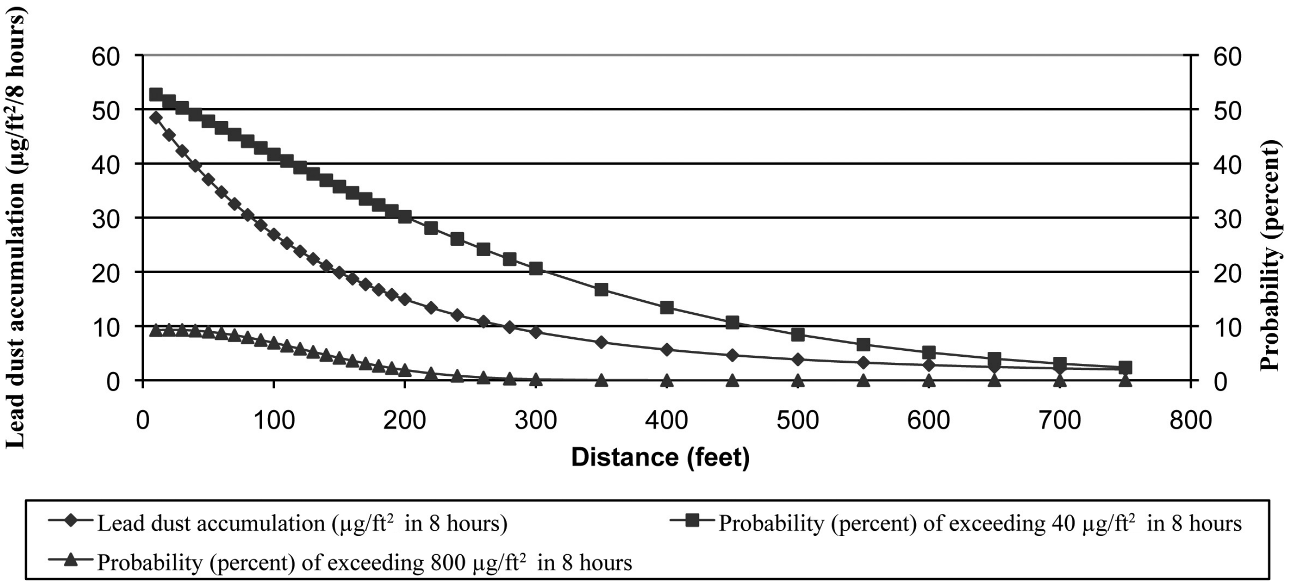
For metals other than lead, many samples were below the RL; however, 428 demolition samples ($n=97$ events) and 73 background samples ($n=34$ events) could be quantified (Table 3). GM lead and cadmium concentrations in ppm were significantly greater in demolition samples than in background samples, and dust fall in μg/ft^2/hr was significantly higher for arsenic, chromium, copper, iron, lead, and manganese in demolition samples (all $p<0.001$).

DISCUSSION

Demolition is conducted in a diverse manner and many factors can contribute to variable dust fall levels. For example, we found that lead dust fall decreased by 17% for each increase in relative humidity of 10%. Relative humidity ranged from 21% to 83% with a mean of 50%. Although the effect of ground saturation was allowed to enter the model, it did not indicate a significant influence, probably because relative humidity was a stronger predictor. One study found that total suspended particulate (TSP) had a negative correlation with relative humidity, but that lead concentration was high in TSP with increasing wind speed.[16] Another study showed that wind direction (but not wind speed) was a significant predictor of lead dust fall.[6] Wind speed may increase the concentration of airborne particulates by aerosolizing settled dusts.

Lead dust fall was 33% lower on side streets than

Figure. Predicted lead dust accumulation after eight hours of single-family housing demolition in Chicago, 2007–2008



µg/ft² = micrograms per square foot

on main streets, possibly due to greater numbers of trees and green landscaping on side streets as well as re-entrainment of particulate from vehicular traffic. We did not sample during winter months to avoid water freezing. Therefore, the results presented in this article cannot be used to estimate dust fall during the winter months, which may be higher due to lack of water dust suppression. Other factors we could not measure in this study included the surface area and concentration of lead-based paint, source of other heavy metals in housing, type and density of housing, extent of occupational exposures, and amount of water actually used.

A study in Baltimore, Maryland, that used the same dust fall sampling methods involved approximately 400 contiguous old row homes in one geographical area that were demolished during a much shorter (three-month) time period. In that study, eight fixed site sampling stations within the demolition area were established, with the demolition proceeding around them, instead of the property-specific perimeter sampling locations in Chicago (Unpublished report, Jacobs DE, Phoenix J, Travis-Miller V, Harris R. Final report of the East Baltimore Development Initiative [EBDI] Advisory Committee. 2010). A much more extensive dust-suppression protocol[13] was established with the support of the EBDI, a local advocacy group (Coalition to End Lead Poisoning), an external independent advisory committee, and others, together with a number of local community meetings. The EBDI dust-suppression protocol included training of all demolition workers in lead-safe work practices; designation of a full-time dust-suppression manager; provision of walk-off mats and high-efficiency particulate air vacuums for residents remaining near the periphery of the demolition zone; landscaping and greening of lots; regular street and sidewalk cleaning; environmental monitoring; installation of jersey barriers and fencing covered with plastic to limit entry and help contain dust; sediment control; and, perhaps most importantly, the extensive use of fire hoses, with one wetting the roof and building exterior and the second wetting the debris on the ground (Photo 5).

The Chicago site had much more limited (and, in some cases, no) dust suppression, fewer houses being demolished, different background lead dust fall, different distances to sampling locations, and a greater likelihood of being on side streets. These differences make a direct comparison with Chicago problematic. In Baltimore, levels were as follows: GM lead dust fall = 0.25 µg/ft²/hour, GM total dust fall = 0.70 µg/ft²/hour, and GM lead in dust fall = 0.25% (Table 4). In Chicago, 6% of the homes exceeded the HUD exterior cleanup standard of 800 µg/ft² after eight hours of demolition; however, in Baltimore, none of them did.

Both the Chicago homes that had water use and the Baltimore results suggest that control of lead dust from demolition in both single- and multifamily housing is feasible. Of the different dust-suppression techniques observed in this study, extensive use of water to wet down building exteriors and debris thoroughly and employment of a dust-suppression manager are likely to help reduce emissions. The Baltimore results also demonstrate that sampling of airborne lead dust (as opposed to dust fall) is less informative, because airborne dust lead results are more likely to be below the limit of detection than is dust fall. This result is probably because lead-contaminated dust is dense and demolition dust is likely to be of larger particle size, both of which suggest it will settle out relatively rapidly and remain airborne for a shorter period of time.

Previous studies of demolition were from large, multifamily housing sites or multiple row homes, where people did not live next door to demolition

Table 3. Geometric mean concentration and dust fall for heavy metals at single-family housing demolition in Chicago, 2008–2009

		Samples		*Metal concentration (ppm)*		*Metal dust fall (µg/ft²/hour)*	
Metal and demolition or background	*Events N*	*N*	*Percent above LRL*	*GM (95% CI)*	*P-value*[a]	*GM (95% CI)*	*P-value*
Arsenic					<0.001		<0.001
Background	34	73	4.1	127 (25, 640)		0.114 (0.042, 0.305)	
Demolition	97	428	17.5	29 (21, 40)		0.605 (0.497, 0.737)	
Cadmium					NA[b]		NA[b]
Background	34	73	0.0				
Demolition	97	428	4.7	8 (4, 13)		0.569 (0.407, 0.794)	
Chromium					<0.001		<0.001
Background	34	73	5.5	226 (47, 1,096)		0.285 (0.145, 0.560)	
Demolition	97	428	14.3	75 (50, 113)		1.841 (1.548, 2.190)	
Copper					<0.001		<0.001
Background	34	73	16.4	191 (87, 420)		0.199 (0.117, 0.339)	
Demolition	97	428	30.1	164 (129, 209)		1.680 (1.429, 1.974)	
Iron					<0.001		<0.001
Background	34	73	38.4	29,084 (18,636, 45,392)		11.559 (7.393, 18.074)	
Demolition	97	428	59.3	25,777 (22,235, 29,882)		101.120 (87.175, 117.300)	
Lead					0.05		<0.001
Background	43	44	77.1	579 (0.039, 2,794)		0.330 (0.219, 0.498)	
Demolition	87	434	92.1	2,406 (957, 8,798)		6.010 (0.927, 2,794)	
Manganese					<0.001		<0.001
Background	34	73	49.3	1,172 (747, 1,838)		0.330 (0.219, 0.498)	
Demolition	97	428	65.9	707 (602, 830)		2.037 (1.759, 2.358)	
Nickel							
Background	34	73	0.0				
Demolition	97	428	0.0				
Selenium					NA[b]		NA[b]
Background	34	73	0.0				
Demolition	97	428	2.6	2.14 (1.04, 4.43)		0.399 (0.291, 0.546)	
Silver					NA[b]		NA[b]
Background	34	73	0.0				
Demolition	97	428	0.5	33.02 (0.06, 1,909)		0.257 (0.196, 0.336)	
Thallium							
Background	34	73	0.0				
Demolition	97	428	0.0				

[a] *P*-value for test that GM metal concentration or dust fall was different at background and demolition locations

[b] Value was too low to calculate the statistic and *p*-value.

ppm = parts per million

µg/ft² = micrograms per square foot

LRL = laboratory reporting limit

GM = geometric mean

CI = confidence interval

NA = not applicable

Photo 5. Extensive dust suppression used at a housing demolition site in Baltimore, with simultaneous water application to roof and to debris pile below. Lead dust fall sampler shown in foreground. Source: East Baltimore Development Initiative

activities. Farfel et al. showed that dust fall lead emissions from multifamily housing demolition can be quite high, because more surfaces are disturbed during a shorter time period.[2,3] However, such sites are typically evacuated during the demolition. But single-family housing demolition is more likely to be conducted in neighborhoods where most residents are still present and where exposure to community members may be greater. There may be higher cumulative exposures due to more frequent exposure and closer proximity to single-family home demolition. The houses in Chicago were only 3 to 5 meters apart from each other, with neighboring properties remaining occupied while demolition occurred.

Distance has been found to be an important factor in other studies. Davies et al. showed that lead in house dust, pavement dust, road dust, and garden soil in those houses located within a 500-meter radius of a demolition site had a higher concentration of 364 µg/gram of lead in soil compared with 267 µg/gram of lead in soil for houses >500 meters from demolition sites.[17] Similarly, interior dust in homes near demolition sites had a lead concentration of 443 µg/gram, whereas homes outside a 500-meter radius of demolition had a mean lead concentration of 417 µg/gram in house dust.[18]

In Chicago, GM arsenic, chromium, copper, iron, and manganese concentrations and dust fall rates were all significantly greater in demolition samples than in background samples (all $p<0.001$). This finding indicates that these metals are a significant component of building materials and demolition dust, perhaps from old pressure-treated lumber that likely has higher levels of copper, chromium, and arsenic. The significantly high lead content (in ppm) as a function of total dust concentration, as well as significant total loading of lead in demolition dust fall, provides strong support for the idea that lead in dust fall comes from residential lead-based paint. The amount of total mass of paint relative to the total mass of other building materials might be expected to be relatively small, but our results indicate that dust from paint is a significant constituent of total dust from housing demolition and supports the hypothesis that the large amount of lead-based paint in housing results in a significant release of lead particulate during demolition.

Limitations

The Chicago study had some important limitations. Because the properties were a convenience sample, there may have been selection bias. Sample location was also constrained to the property perimeters for safety reasons. Given the distance effect reported in this article, it is likely that dust fall is much higher within the actual demolition site. We also could not measure occupational exposure, which is an area for future investigation. Additionally, the impact of cleaning sidewalks and streets (which was done in Baltimore but not in Chicago) was not quantified and is another

Table 4. Baltimore demolition results where more extensive dust suppression was used, 2008–2009

Variable	*Samples N*	*Percent below LRL*	*GM (GSD)*	*25th percentile*	*50th percentile*	*75th percentile*
Lead dust fall (µg/ft²/hour)	238	66	0.25 (3.57)	1.28	2.01	4.49
Lead percentage	226	65	0.25 (3.54)	0.23	1.21	2.85
Total dust fall (µg/ft²/hour)	237	5	0.70 (2.34)	1,996	4,201	6,234

LRL = laboratory reporting limit

GM = geometric mean

GSD = geometric standard deviation

µg/ft² = microgram per square foot

potential area for future research. Lastly, the lead content of interior and exterior paint and other heavy metals was not determined prior to demolition activities, although all the homes were old and, therefore, highly likely to contain lead-based paint.

CONCLUSIONS

Further research is needed to determine if dust-suppression methods such as water and cleanup are effective in controlling both community and occupational exposures to metals other than lead. The use of water to reduce dust emissions from demolition has been acknowledged for more than a century.[19] Tjoe Nij et al. found that wetting construction and demolition material so that it was moist significantly reduced the amount of respirable dust by a factor of 2.8 for workers.[20] However, that study also found that only 16% of workers routinely used water to suppress dust, suggesting the need for a dust-suppression manager, as was the case in the EBDI protocol.[13] Future research should examine whether some types of nozzle configurations on hoses at demolition sites do a better job of containing dust fall and how to control contamination from runoff. The principal method of controlling contaminated water runoff from the site in Baltimore was placement of sandbags over storm sewers to capture lead in the water before it entered the sewer, but no data were available to determine if this method was adequate.

Large amounts of dust contaminated with lead and other heavy metals are generated from demolition of older housing, which is likely to contain lead-based paint and other building materials with heavy metals. Dust suppression is feasible in housing demolition and may also be effective for the other heavy metals we found in demolition dust fall. Its use is especially important in single-family housing demolition, where distances to nearby occupied housing are smaller and community exposures are likely to be higher. Community member notification should be widened to at least 400 feet from the demolition site, not just the next-door neighbors, as is now commonly the practice in single-family housing demolition.

This study was approved by the Institutional Review Board of the University of Illinois at Chicago.

The authors thank the community members who gave their time to be interviewed for this project and Victoria Persky, Peter Scheff, Latonya Cannon, John Bartlett, and Richard Gilliam for their assistance in project conceptualization and data collection. This project was supported by the U.S. Department of Housing and Urban Development Grant #ILLHT 0110-06 and the National Institute of Occupational Safety and Health Grant #T42/OH008672. The views expressed in this article are those of the authors and do not necessarily represent the views of the U.S. government.

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