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# Longevity of the effectiveness of interim soil lead hazard control measures and influencing factors

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ABSTRACT

A 7-year follow-up was conducted to determine factors associated with the longevity of interim soil lead hazard control measures that had been applied to housing in the Cleveland OH area. The approach involved (1) visual determination of the treatment integrity, (2) collection of information regarding 14 factors that may contribute to longevity of treatment integrity and (3) collection of one composite soil sample from treated areas with visual failure at each house and another composite sample from areas without visual failure. For the 200 houses studied, an average of 4 different soil areas were treated. For 96% of these areas, the treatments used were: (1) re-seeding, (2) mulch/wood chips and (3) gravel. Of a total of 191,034 $ft^2$ of treated soil areas observed, less than one-third, i.e. 59,900 $ft^2$ (31.3%) exhibited visual failure at the time of follow-up. Hazard control method and the presence/absence of shade were the only factors found to significantly affect visual failure rates. Of the three most commonly used control measures, the lowest visual failure rate was for re-seeding, 29.1% after a mean of 7.3 years; for non-shaded areas, which had been re-seeded, the failure rate was 22.2% compared to 35.7% for shaded areas. At 116 of the 193 houses (60%) that had both visually failed and visually non-failed treated soil areas, the geometric mean soil lead concentration was higher in the failed areas ($p=0.003$). The actual difference was only 13% with most levels equal to or exceeding 400 ppm. However, when compared to the US EPA limit for bare soil in other residential areas (1200 ppm) the percent equal to or exceeding the limit was much higher in the visually failed areas, 33.1%, than in areas where such failure was not observed, 22.0%.



## 1. Introduction

The literature is very limited on the longevity of the effectiveness of interim soil lead hazard control treatments. Dixon et al. (2006) found that the application of ground coverings and ground barriers continued to block access to the lead-contaminated soil at 1 year follow-up. However, even after only 1 year few of the properties with grass treatment had areas that were completely bare and 28% had more than a small amount of treated areas bare. Binns et al. (2006) conducted a 1-year follow-up of: ground coverings/barriers with a raised garden bed, use of ground coverings/barriers only and a control group where no treatments were implemented. They found that soil lead concentrations were reduced in the two treatment groups and increased somewhat in the control group after 1 year. Dust lead levels on entryway floor mats in houses where the two treatments were applied were lower than in the control group.

Estimates included in the Protocol Document for the Evaluation of the HUD Lead-Based Paint Hazard Control Program (National Center for Healthy Housing (1994)) were that covering contaminated soil with mulch or stones, considered a "Minimum Response to Elevated Soil" would last 1–2 years. A very wide range of 5–20 years was given for the estimates of the length of time that covering contaminated soil with 6 in of low lead soil would be effective.

In a study involving housing across the country where soil lead hazard controls had been performed, the use of interim soil lead hazard control was found to be associated with lower dust lead levels within the housing (Clark et al. 2004), between 1 and 3 years after intervention. Most of the soil lead hazard control measures were defined as interim. Although little documented evidence is available on the longevity of their effectiveness, these interim treatments have been estimated to be effective only for periods up to about 5 years.

In an earlier follow-up to this study (impact of soil lead hazard control activities on exterior and interior dust lead loadings OHLTS0094-02) limited observations were made of the visual appearance of soil areas of housing in the City of Cleveland, OH,

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where lead hazard control treatments had been applied. These treatments were primarily interim control methods and were performed 3–6 years prior to the time of the observation. For the few sites where paving stones were installed, the entire area treated still appeared to be in satisfactory condition. However, when the observations of the areas treated by all methods combined were compared by number of years since lead hazard controls were implemented, there was not a consistent trend by years elapsed since intervention. The lack of a trend with time may have been due to the fact that information on "intensity of use" of the treated area and extent of maintenance performed by the occupant/owner or manager were not determined. Information such as the location of the treated area with respect to high use activities such as driveways, car parking spaces and sidewalks and the actual use of the areas such as for actively used play equipment was also not determined. Soil lead levels of all treated areas were not determined. Because of the need for data on the longevity of interim soil lead hazard control measures, a decision was made to explore these findings through more detailed observations of conditions at the treated areas.

The current study was an effort to obtain more information on the visual treatment longevity of interim soil lead hazard control, an examination of some of the factors that may influence the treatment longevity and soil lead concentrations in areas with visual evidence of treatment integrity failure and without visual failure. Factors examined that may influence the longevity of the treatments included measures of the intensity of uses of the treated areas and the use of adjacent areas. Such information may be useful in decision-making regarding the appropriateness of certain controls for the conditions at specific areas. This study was a follow-up of interim soil lead hazard control measures applied to soil areas of 200 residential buildings in Cleveland, OH, and Cuyahoga County, OH, under several HUD Lead-Based Paint Hazard Control Grants to the City of Cleveland, OH, and Cuyahoga County, OH Board of Health. Field work was performed by staff of Environmental Health Watch of Cleveland, OH, a community-based organization.

## 2. Methods

The objectives of this study were to determine the failure rates of several interim soil lead hazard control measures 3–11 years after intervention by visual observations of treatment integrity, assess the contribution of factors that may impact treatment integrity and assess current risk by composite soil lead levels for all areas at a property that exhibited visual treatment failure and for all areas at a property that did not exhibit such failure. These observations were used to determine the factors that appear to influence the longevity of their effectiveness such as the numbers of children and adults using the area, the presence of shade and uses of the treated and adjacent areas.

### *2.1. Selection of housing*

Housing sites were selected from those treated by both the Cleveland, OH Department of Public Health and the Cuyahoga County, OH Board of Health to insure that a total of 200 buildings were available where a variety of interim soil lead hazard control measures had been used. Soil lead hazard control measures had previously been implemented for these housing under Rounds One, three and eight of the HUD Lead-Based Paint Hazard Control Grants to the City of Cleveland, OH, and grants to Cuyahoga County, OH. The types of soil lead treatments were primarily interim controls. At few of the houses there was some soil replacement. Because high soil lead concentrations are common in the yards of older housing in the neighborhoods where housing in this follow-up were located, it was a general practice to implement a soil lead hazard control procedure on all bare areas at housing where perimeter soil sample indicated a lead hazard. The soil lead hazard control measures used were:

- Re-seeding: roto-till, grade, seed, fertilize and cover with straw.
- Mulch/wood chips: roto-till, grade, apply weed block, and 4 in mulch or wood chips.
- Gravel: roto-till, toe-in, add 4 in of 411 gravel, compact. Toe-in refers to an excavation where the bottom of the excavated area is wider than the top. (This would tend to minimize the extent of the gravel moving to an adjacent area over time.)
- Sod: roto-till and then apply sod.
- Paving blocks.
- Paved with asphalt.
- Soil replacement: excavate 6 in of soil, add replacement soil and then apply sod.

Information on the type of treatment implemented and the location and size of the area treated were obtained from records of the local agencies involved in administering the lead hazard control grant programs. The grass seed used was the type that was appropriate for the relative degree of shade and sunlight at the area involved.

### *2.2. Soil sample collection*

At each residence two composite soil samples were collected: one from previously treated areas where visual failure of lead hazard control treatments was observed and one from the treated soil areas where visual treatment failure was not observed. Ten to twelve sub-samples were collected from each of these areas where bare soil was visible. Soil samples were collected using a 1 in diameter stainless steel coring device (Arts Manufacturing and Supply Company Inc.). The top 2 cm cores of the soil were collected. The composite sample cores were collected in proportion to the relative size of the areas involved. If failure was observed and no bare soil was present but there appeared to be soil on the top of a fabric that had been placed on top of the contaminated soil prior to the placement of bark, mulch, gravel, etc. the soil on top of the fabric was collected. The protective fabric was not penetrated to collect soil beneath the fabric.

During the years since the soil lead hazard control interventions were applied, many different families have typically occupied the houses in this study. The habits of the children in these different families regarding which areas are used for playing or other activities would vary and thus the areas that were used for playing or related activities would likely change as new families occupied the housing. In addition, for individual children, habits and activity areas are also likely to change as the children grow older. Because of these factors and that the yards themselves are generally rather small, we think that the entire soil area should be regarded as either a current play/activity area for children or a potential one.

### *2.3. Soil sample processing and analysis*

All soil samples were processed and analyzed in the Hematology and Environmental Laboratory (H & E) at the University of Cincinnati. The laboratory is accredited by the American Industrial Hygiene Association as an industrial hygiene laboratory and also as an environmental lead laboratory under the National Lead Laboratory Accreditation Program. Consequently, the laboratory participates in the PAT and ELPAT proficiency programs and is recognized by the National Lead Laboratory Accreditation Program (NLLAP). For every 25 samples 1 sample was selected for duplicate analyses. For every 20 samples, 1 sample was selected for determination of recovery. Samples were sieved with a 250 $\mu$m or #120 stainless steel sieve. Samples were not ground.

Sample aliquots were digested following a modification of NIOSH 7082 and analyzed by flame-atomic absorption spectroscopy (FAAS) (10). Sample digestates were analyzed by flame-atomic absorption spectroscopy (FAAS) according to EPA SW846 method 7420.

### *2.4. Treatment longevity*

At each residential site the date at which the use of soil control measures was completed was obtained from available records. The duration of time between the completion of the soil lead hazard control measure and the date of the field visits to observe the visual condition of the treatment was calculated for each house. Copies of the original specifications, and in many cases the drawings for the soil treatments were available to the field technicians. Each treated area was located and evaluated for the extent of visual failure. For example, the mulch/wood chip treatments included installation of a fabric cloth on top of the tilled soil before placement of the chips/mulch. Any visible area of underlying fabric was considered to be a visual treatment failure for that specific area. Criteria for visual failure of each of the specific treatments are summarized in Table 1.

An estimate was made of the size of the area(s) where a specific treatment exhibited visual failure compared to the size of the original treatment area. These figures were converted to a ratio of visually failed area to total treated area for each treatment at each housing site.

Portions of the treated areas exhibiting visual evidence of failure were generally of the order of a square foot or more. After determining the size of a treated area, the approximate percentage showing visual signs of treatment failure was assessed visually to about the nearest square foot, or nearest 5%, whichever

**Table 1**
Definitions of visual failure of soil lead hazard control treatments.

| Treatment | Failure characteristics |
|---|---|
| 1. Re-seed | Bare soil present in treated area |
| 2. Mulch/wood chips | Visible soil or black plastic that was placed on soil before mulch/wood chips were applied |
| 3. Gravel | Visible soil in area where gravel was placed |
| 4. Sod | Bare soil present in treated area |
| 5. Paving stones | Paving stones missing and/or soil exposed between stones |
| 6. Paved with asphalt | Asphalt missing or with deep cracks |
| 7. Soil replacement+-sod | Bare soil present in treated area |

**Fig. 1.** Photo of re-seeded soil areas without visual failure.

**Fig. 2.** Photo of mulch/wood chip treatment with high percentage of failure and re-seeded area with minimal failure.

was easier to do, and then converted, as needed, to square feet. Cracks in asphalt containing vegetation or visible dirt were judged as a failure.

Fig. 1 is a photo of soil area where the soil area that was re-seeded is shown to have grass that now fully covers the area and was judged to have no visual evidence of treatment failure. Fig. 2 is a photo of an area behind a garage where only 15 of 300 $ft^2$ of area treated by use of mulch/wood chips was judged to not show visible failure. The light areas are plastic sheeting that was placed under the mulch/wood chips at the time of the intervention. Just in front of the cinderblock divider a small amount of bare soil (estimated 15 $ft^2$ out of 1200 $ft^2$ treated by re-seeding). Only 1 subsample was collected from this area for the failed composite sample for this house.

### 2.5. Factors potentially effecting treatment longevity

Data were also collected on the following 14 factors that may influence the longevity of the treatments:

- Uses of area adjacent to the treated area (walkway, driveway, street, building) that could impact the conditions of the treated areas.
- Uses of treated area (auto parking, play equipment) that could impact the conditions of the treated areas.
- Intensity of use (e.g. approximate number of children and adults using area, and the number of hours per week used, during the outdoor season, and whether or not actively used by dogs or other pets).
- Whether the resident or owner provided maintenance of the treated area or not.
- Presence or absence of shade in the treated areas.
- Type of treatment.

In order to obtain some of the data it was necessary to interview residents and/or owners. An existing field data collection form (Form 28) used in the HUD.

Evaluation (National Center for Healthy Housing (2004)) was modified to record: conditions observed in the treated soil areas, factors possibly influencing visual soil treatment failure and soil sample collection details. The modifications also facilitated the linking of the soil samples collected with the type of treatment that the area received.

The form is protocol was pilot tested on five homes. Form 30 is presented in Attachment A.

### 2.6. Data quality measures and analysis

Several procedures were utilized to ensure the validity of the collected data. One member of the research team completed the form, while a second member reviewed the form for errors. Completed forms were forwarded to the Field Manager who verified the legibility and completeness of the entries. Forms were then delivered to the University of Cincinnati Project Coordinator where they were entered into the data management system (Microsoft Access database). Computerized data files were checked for data entry errors by an individual not performing the data entry.

Before major statistical analyses were performed on any of the data, univariate analyses of the frequency distributions were reviewed. These descriptive statistics provided valuable information for choosing the best variable specification (transformation of the observed frequency distribution, e.g., log, square root, etc.) for each variable in the database. A mixed model analysis of covariance was used to determine the impact of multiple factors that may contribute to visible treatment failure.

### 2.7. Human subjects research approval

The project protocol was approved by the University of Cincinnati Medical Center Institutional Review Board (IRB).

## 3. Results

Descriptive statistics of the types of interventions performed on the soil areas of the 200 houses in the study are presented in Table 2 along with the size of the areas where applied, the time between intervention and follow-up, the number of visual treatment observations performed and the ratio of visually failed area to total area for each treatment.

For the 200 houses studied, visual treatment observations were performed on an average of 4 different soil areas for each house. For 96% of these areas, the treatments used were: (1) re-seeding, (2) mulch/wood chips and (3) gravel. Of the total of 191,034 $ft^2$ of treated soil areas observed, the ratio of visually failed treatment area to total area was 0.314, or 31.4%. Of the three most commonly used control measures, the lowest visual failure rate was for re-seeding, 0.291 (29.1%) after a mean of 7.3 years since intervention.

**Table 2**
Description of soil lead hazard control measures applied.

| Treatment specification number (description) | Total soil area where applied ($ft^2$) | Time between intervention and follow-up. Mean, years | Range of time | Number of treatment condition observations (%) | Ratio of visually failed area to total treated area |
|---|---|---|---|---|---|
| 1. Re-seeding | 119,764 (62.7) | 7.3 | 2.7–11 | 350 (42.4) | 0.291 |
| 2. Mulch/wood chips | 46,339 (24.3) | 7.4 | 3–11 | 337 (40.8) | 0.420 |
| 3. Gravel | 16,475 (8.6) | 7.6 | 4.3–11 | 106 (12.8) | 0.361 |
| 4. Sod | 4335 (2.3) | 9.5 | 8.3–9.8 | 16 (2.0) | 0.252 |
| 5. Paving stones | 237 (0.1) | 8.8 | 8.3–9.7 | 5 (0.6) | 0.473 |
| 6: Paved with asphalt | 2086 (1.0) | 5.9 | 4.8–9.2 | 7 (0.9) | 0.575 |
| 7. Soil replacement+sod | 1798 (0.9) | 9.7 | 9.7–9.7 | 4 (0.5) | 0.456 |
| Overall | 191,034 | 7.4 | 2.7–11 | 825 | 0.314 |

**Table 3**
Mixed model of covariance tests of fixed effects using all factors potentially influencing longevity.

| Effect | Num DF | Den DF | *F*-value | Pr > *F* |
|---|---|---|---|---|
| Child hours/week | 1 | 566 | 0.83 | 0.3630 |
| Number of children | 1 | 566 | 0.15 | 0.7010 |
| Adult hours/week | 1 | 566 | 0.09 | 0.7586 |
| Number of adults | 1 | 566 | 0.07 | 0.7911 |
| Spec. number | 6 | 238 | 3.24 | 0.0045 |
| Adjacent to walkway | 1 | 122 | 0.46 | 0.4994 |
| Adjacent to driveway | 1 | 112 | 0.41 | 0.5229 |
| Adjacent to street | 1 | 97 | 1.25 | 0.2656 |
| Adjacent to building | 1 | 110 | 0.76 | 0.3978 |
| Auto parking | 1 | 117 | 0.08 | 0.7338 |
| Play equipment | 1 | 122 | 0.44 | 0.5603 |
| Who maintains | 2 | 191 | 2.30 | 0.1164 |
| Shade | 1 | 86 | 17.89 | < 0.0001 |
| Pets | 1 | 5 | 0.21 | 0.6657 |
| Year | 1 | 19 | 1.59 | 0.2090 |

**Table 4**
Type 3 tests of fixed effects after elimination all factors potentially influencing treatment longevity except one non-significant factors.

| **Effect** | **Num DF** | **Den DF** | ***F*-value** | **Pr > *F*** |
|---|---|---|---|---|
| **Spec. number** | 6 | 241 | 3.57 | 0.0021 |
| **Who maintains** | 2 | 194 | 2.18 | 0.1159 |
| **Shade** | 1 | 86 | 20.69 | < 0.0001 |

**Table 5**
Impact of shade on ratio of visual treatment failure area to total treated area least squares means.

| **Effect** | **Shade** | **Estimate** | **Standard error** | **DF** | ***t*-Value** | **Pr > \|*t*\|** |
|---|---|---|---|---|---|---|
| **Shade** | **N** | 0.1928 | 0.04,947 | 86 | 3.90 | 0.0002 |
| **Shade** | **Y** | 0.3287 | 0.04,835 | 86 | 6.80 | < 0.0001 |

### *3.1. Examination of factors potentially contributing to visual treatment failure*

Of the 14 factors examined that may have an impact on the longevity of soil lead hazard control measures only 2 were found to be statistically significant—the type of hazard control used and the presence or absence of shade (Table 3).

The model was re-run a number of times, each time dropping the factor with the least significant effect. In the final model (Table 4) only the same 2 factors remained significant: shade and treatment specification number (Spec. Number). The interim control treatment "re-seeding" had a significantly lower rate of visual failure than "mulch/wood chips".

An examination of the effect of shade on visual treatment failure (Table 5) revealed a visual failure ratio of 0.1928 for areas without shade compared to 0.3287 for areas with shade. The presence of shade thus increased the visual failure by about 70%.

An examination of the effect of the factors potentially influencing visual treatment longevity was performed for the three most common interim controls separately. For re-seeding, shade was the only significant factor with the presence of shade increasing the failure rate by 46% higher than with no shade. For the mulch/wood chip treatment, shade also increased the failure rate. For this treatment maintenance was also significant, with failure being least if the area was maintained by the owner, slightly higher failure if no one was assigned this responsibility and highest if the resident maintained the area. For the gravel control measure there were no significant factors detected.

A number of the potentially contributing factors whose presence was thought to possibly reduce the longevity of the treatment process are indications of the uses that are adjacent to the treated soil area. These factors (adjacent to walkways, driveways, streets and buildings) were combined into an overall factor of all adjacent areas. Similarly, an overall intensity of use factor was created, which is the sum of the number of children on the property times the average hours of use and the number of adults times the average hours of use. A re-run of the model revealed that these 2 new factors did not reach statistical significance and after eliminating the most insignificant term, one at a time, the same conclusion is reached as shown in Table 4.

### *3.2. Soil lead concentration*

Since the two soil samples collected from each house were composite samples from all areas, which exhibited a visual failure of the soil treatment and a composite from the areas that did not have visual treatment failure, the lead concentrations cannot be related to specific soil lead hazard control treatments. Soil lead concentrations can also not be related to specific uses of the soil area such as for playing. Since the uses of the soil areas change as occupancy changes, and also as children develop different habits, all areas of these relatively small yards can be regarded as either used by children for playing or other activities or potentially being used for such purposes. Therefore, the soil lead concentrations from areas with and without visual failure were compared with the two US EPA limits for lead concentrations in soil in residential areas: bare soil in play areas (400 ppm) and other bare residential soil (1200 ppm).

Geometric mean soil lead concentrations (Table 6) were statistically significantly higher in the areas observed to have a visual treatment failure ($p=0.003$), the actual difference in the mean concentrations was only 13%. The percent of the soil samples that were equal to or exceeded the US EPA limit for bare

**Table 6**
Distribution of soil lead concentration in the treated areas with and without visible treatment integrity failures.

| Quantile | Soil lead concentration, ppm, in areas with visible treatment integrity failure ($n=196$) | Soil lead concentration, ppm, in areas with no visible treatment integrity failure ($n=195$) |
|---|---|---|
| 100% Max | 13,278 | 24,672 |
| 99% | 5175 | 8374 |
| 95% | 2639 | 2574 |
| 90% | 2154 | 1568 |
| 75% Q3 | 1359 | 1107 |
| 50% Median | 870 | 770 |
| 25% Q1 | 584 | 492 |
| 10% | 397 | 374 |
| 5% | 296 | 317 |
| 1% | 105 | 114 |
| 0% Min | 97 | 92 |

soil in play areas (400 ppm) was similar in areas with and without visible treatment failure, 89.8% and 86.7%, respectively. Compared to the US EPA limit for bare soil in other residential areas (1200 ppm) the percent equal to or exceeding the limit were very different: 33.1% and 22.0%, respectively.

## 4. Discussion

Since three interim soil lead hazard control treatments, re-seeding, mulch/wood chips and gravel, comprised 96% of the soil lead hazard control measures applied to soil areas of the 200 houses in this study, conclusions apply primarily to these three control measures. It is interesting to note that even though the literature suggests that interim soil lead hazard will be effective for up to 5 years, these three control measures had visual evidence of failure rates of only 27%, 40% and 34%, respectively, after an average of between 7.2 and 7.6 years post-intervention.

Many different families have typically occupied the houses in this study and the habits of the children regarding which areas are used for playing or other activities would thus vary over time. In addition, for individual children, habits and activity areas are likely to change as the children mature. Because of these factors and that the yards themselves are generally rather small, there is justification to consider the entire soil area as either a current play/activity area or a potential one.

It might be expected that the significantly lower failure ratios that were found for non-shaded areas might be due to more use of the shaded area by children and adult. To examine this possibility, we considered the impact of the number of children and adults who used the soil areas, and the estimated number of hours of use. These factors did not have a significant impact on the failure ratio, when examined separately or as a combined use factor (number of children and adults using the area multiplied by the hours of use by each group. The presence of shade increased the treatment failure for both the re-seeding and mulch/wood chip treatments. A plausible explanation for this for the re-seeding treatment may be that grass needs sunlight to thrive but no such explanation for the mulch/wood chip treatment has thus far been found.

Although the duration of time between the soil lead hazard control intervention and the follow-up conducted in this study was not a significant factor influencing visual failure, the mean duration for the three soil lead hazard control measures utilized for the vast majority of the treated areas (96%) varied only slightly, from 7.2 to 7.6 years.

Since the soil samples collected were composites from areas exhibiting either visual evidence of failure or no visible evidence of failure, from areas treated by all control measures applied at a given house, the soil lead concentration data cannot be related to particular control measures. It would be interesting to obtain data from visually failed/non-failed areas for each control measure separately. Since the mulch/wood chips control measure utilized a plastic barrier on top of the contaminated soil before application of the mulch/wood chips, a visual failure of this control measure that was the observance of plastic barrier, would not by itself result in the contaminated soil being at the surface. Thus soil on top of the plastic barrier, which was sampled when available in this study, would be expected to have a lower lead concentration than that from a visually failed re-seeding or gravel treatment. The latter two treatments involved performing the re-seeding and application of the gravel with the contaminated soil being left in place. If grass was not present, the definition of visually failed re-seeding, the soil sampled would be the soil that was found to be contaminated at the time of the intervention. Similarly, for the gravel control measure, the absence of the gravel (the definition of visual failure) would result in the original contaminated soil being at the surface and would thus be sampled.

Possible reasons for the higher likelihood of failure in shaded areas include (1) higher moisture content and thus greater risk of attack from termites/soil micro-organisms, and (2) shaded areas may have more activity during warmer months, because of the relative coolness provided by the shade, and that this activity by children and adults could result in a scattering of the wood chips and the exposure of the underlying plastic resulting in an visual failure. However, an examination of the intensity of use of the areas by children and adults did not show it to be a significant factor in predicting visual failure.

The soil samples that were collected were composite samples from all failed areas of treated soil on the property and from all unfailed areas on a property and thus do not reflect individual soil lead hazard control measures used. The similarity of soil lead concentrations in the two areas may be due in part to migration of surface soil between areas with and without visual treatment failure and from untreated areas on the same house site or on adjacent sites. The visual integrity of the hazard control treatment was only measured at one time and may not reflect an overall measure of visual condition of the treatment integrity over the duration of time since the intervention.

The similarity in duration of time between intervention and follow-up for the three most commonly used interventions (mean of 7.4–7.6 years) may have contributed to the finding that duration did not have a significant impact on visual failure of treatment.

## 5. Limitations

Since individual soil samples were not collected from areas treated by specific hazard control measures, soil lead concentrations cannot be related to specific treatments. Similarly, another important limitation is due to the fact that soil lead concentrations cannot be related to specific uses such as play areas. Another limitation of the soil lead data was that data were not collected from soil areas at the house that were not treated under the HUD Lead-Based Hazard Control Grants and were not collected from adjacent properties. Since there was limited soil lead sampling prior to intervention and decisions on which area to apply treatments was generally based on whether or not the soil cover was bare, it is possible that the soil lead concentration in untreated areas was higher than that in treated areas.

Because of the length of time between intervention and follow-up, non-bare areas that may have had high soil lead areas at the time of intervention and were thus not-treated, may have become bare in the intervening years because of changes in use and may contribute to the lead level of previously treated areas.

## 6. Conclusions

Of the total of 190,034 $ft^2$ of soil areas of the 200 houses in this study that had previously received a soil lead hazard control treatment, 31.4% exhibited visual failure of the integrity of the hazard control treatment after a mean time since intervention of 7.4 years.

Of the 14 factors potentially influencing factors that were examined that may have an impact on the longevity of soil lead hazard control measures, only 2 were found to be statistically significant—the type of hazard control used and the presence or absence of shade. Of the three most commonly used soil lead hazard control measures, the use of re-seeding of the existing soil had the lowest visual failure rate: 29% of the soil area where this method was used showed visual evidence of failure after a mean of 7.3 years. The visual failure rate for non-shaded soil areas treated by re-seeding was 22.2% compared to 35.7% for shaded areas. The presence of shade thus increased the visual failure by about 61%. Duration of time between soil lead hazard control intervention and the follow-up was not found to have a significant impact on visual treatment failure.

For the 193 houses that had both visually failed and visually not failed soil areas, the soil lead concentration was higher in the visually failed areas at 116 houses (60%), higher in the unfailed areas at 76 houses (39%) and the same at 1 house (0.5%).

Although soil lead concentrations were statistically significantly higher in the areas observed to have a visual treatment failure ($p=0.003$), the actual difference in the mean concentrations was only 13%. The percent of the soil samples that were equal to or exceeded the US EPA limit for bare soil in play areas (400 ppm) was similar in areas with and without visible treatment failure, 89.8% and 86.7%, respectively. Compared to the limit for other residential areas (1200 ppm) the differences were much greater, 33.1% and 22.0%, respectively.

## References

Binns, H.J., Gray, K.A., Chen, T., Finster, M.E., Peneff, N., Schaefer, P., Ovsey, V., Fernandes, J., Brown, M., Dunlap, B., 2006. Evaluation of landscape coverings to reduce soil lead hazards in urban residential yards: The Safer Yards Project. Environmental Research 96, 127–138.

Clark, C.S., Menrath, W., Chen, M., Succop, P., Bornschein, R., Galke, W., Wilson, J., 2004. The influence of exterior dust and soil lead on post-intervention interior dust lead levels in housing in the evaluation of the HUD Lead-Based paint hazard control program. Journal of Occupational and Environmental Hygiene 1 (5), 273–282.

Dixon, S.L., McLaine, P., Kawecki, C., Maxfield, R., Duran, S., Hynes, P., Plant, T., 2006. The effectiveness of low-cost soil treatments to reduce soil and dust lead hazards: the Boston lead safe yards low cost lead in soil treatment, demonstration and evaluation. Environmental Research 102, 113–124.

National Center for Healthy Housing, 1994. Protocol Document for the Evaluation of the HUD Lead-Based Paint Hazard Control Program, Columbia, MD.

National Center for Healthy Housing (NCHH) and University of Cincinnati Department of Environmental Health (UC), 2004. Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program, Final Report, Washington, DC.