

**Proposed Approach for Developing Lead Dust Hazard Standards  
for Commercial and Public Buildings**

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1 **1. Introduction**

2 Section 402(c)(3) of TSCA directs EPA to revise the regulations promulgated under TSCA  
3 section 402(a), *i.e.*, the Lead-based Paint Activities Regulations, to apply to renovation or  
4 remodeling activities in target housing, public buildings constructed before 1978, and  
5 commercial buildings that create lead-based paint hazards. In April 2008, EPA issued the final  
6 Renovation, Repair and Painting Rule (RRP Rule) under the authority of section 402(c)(3) of  
7 TSCA to address lead-based paint hazards created by renovation, repair, and painting activities  
8 that disturb lead-based paint in target housing and child-occupied facilities (USEPA, 2008a). The  
9 term “target housing” is defined in TSCA section 401 as any housing constructed before 1978,  
10 except housing for the elderly or persons with disabilities (unless any child under age 6 resides or  
11 is expected to reside in such housing) or any 0- bedroom dwelling. Under the RRP Rule, a child-  
12 occupied facility is a building, or a portion of a building, constructed prior to 1978, visited  
13 regularly by the same child, under 6 years of age, on at least two different days within any week  
14 (Sunday through Saturday period), provided that each day’s visit lasts at least 3 hours and the  
15 combined weekly visits last at least 6 hours, and the combined annual visits last at least 60 hours.  
16 The RRP Rule establishes requirements for training renovators, other renovation workers, and  
17 dust sampling technicians; for certifying renovators, dust sampling technicians, and renovation  
18 firms; for accrediting providers of renovation and dust sampling technician training; for  
19 renovation work practices; and for recordkeeping. Interested States, Territories, and Indian  
20 Tribes may apply for and receive authorization to administer and enforce all of the elements of  
21 the RRP Rule.

22 Shortly after the RRP Rule was published, several petitions were filed challenging the rule.  
23 These petitions were consolidated in the Circuit Court of Appeals for the District of Columbia  
24 Circuit. On August 24, 2009, EPA entered into an agreement with the environmental and  
25 children’s health advocacy groups in settlement of their petitions (USEPA, 2009a). In this  
26 agreement, EPA committed to propose several changes to the RRP Rule. EPA also agreed to  
27 commence rulemaking to address renovations in public and commercial buildings, other than  
28 child-occupied facilities, to the extent those renovations create lead-based paint hazards. For  
29 these buildings, EPA agreed, at a minimum, to do the following:

- 30 • Issue a proposal to regulate renovations on the exteriors of public and commercial  
31 buildings other than child-occupied facilities by December 15, 2011 and to take final  
32 action on that proposal by July 15, 2013.
- 33 • Consult with EPA’s Science Advisory Board by September 30, 2011, on a methodology  
34 for evaluating the risk posed by renovations in the interiors of public and commercial  
35 buildings other than child-occupied facilities.
- 36 • Eighteen months after receipt of the Science Advisory Board’s report, either issue a  
37 proposal to regulate renovations on the interiors of public and commercial buildings other  
38 than child-occupied facilities or conclude that such renovations do not create lead-based  
39 paint hazards.

40

1 In order to evaluate the potential risks associated with lead exposure due to renovations in public  
2 and commercial buildings, and the potential need for regulations on these activities, it is first  
3 necessary to develop the hazard standards for lead dust on window sills and floors in public and  
4 commercial buildings; these become the standards to help inform the impact of renovation  
5 activities. These standards will identify dangerous levels of lead in paint and dust, and provide  
6 benchmarks on which to base remedial actions taken to safeguard children and the public from  
7 the dangers of lead. This document describes OPPT’s proposed approach for developing the  
8 dust-lead hazard standards for floors and window sills in commercial and public buildings.  
9 OPPT will consider hazard standards for children and adults, as there may be some public and  
10 commercial buildings which children are unlikely to visit. Figure 1-1 provides an overview of  
11 the approach for developing hazard standards for public and commercial buildings. The  
12 approach is made up of three primary steps:

- 13 • Select target blood lead concentration
- 14 • Estimate environmental media and exposure concentrations; and
- 15 • Estimate blood lead concentrations.

16 The first step, *Select Target Blood Lead Concentration*, involves the selection of target blood  
17 lead levels for children and adults. For children, the proposed approach will focus on target  
18 blood lead levels that are associated with IQ effects in children; three target blood lead levels  
19 have been selected which are at the low end of the concentration-response curve. For adults, the  
20 proposed approach will focus on target blood lead levels that are associated with blood pressure  
21 effects in adults; several target blood lead levels have been selected which are at the low end of  
22 the concentration-response curve. The remaining steps of the approach will then be applied to  
23 estimate the candidate dust-lead levels (hazard standards) for floors and window sills that do not  
24 result in blood lead levels exceeding the target levels in children and adults.

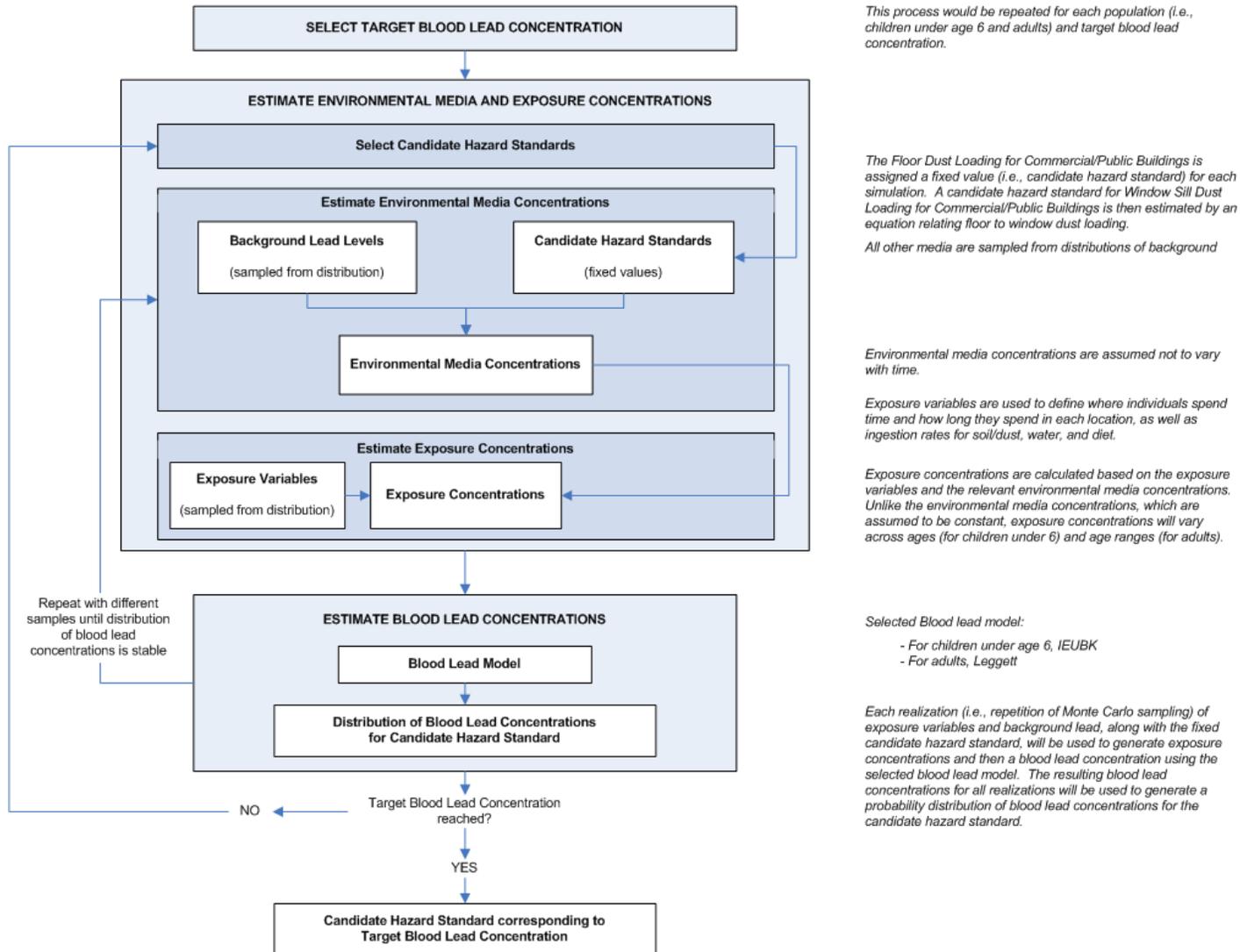
25 The second step, *Estimate Environmental Media and Exposure Concentrations*, involves  
26 characterizing lead concentrations in relevant environmental media and using these data, in  
27 conjunction with information about human behavior patterns, to estimate lead exposures for the  
28 modeled populations. This step consists of three parts: selecting dust-lead levels for window  
29 sills and floors (candidate hazard standards), estimating environmental media concentrations, and  
30 estimating exposure concentrations.

31

32

1 **Figure 1-1. Overview of Approach for Developing Hazard Standards for Commercial and Public Buildings**

2



3

- 1 • *Select candidate hazard standard.* For each selected potential blood lead level of  
2 concern, an initial candidate hazard standard for floor dust loading will be selected and  
3 carried through the remaining steps of the approach. The candidate hazard standard for  
4 window sill dust loading will be calculated based on the candidate hazard standard for  
5 floor loading using an estimated relationship between floor dust and window sill dust  
6 loadings.
- 7 • *Estimate environmental media concentrations.* The approach uses total blood lead  
8 concentrations, rather than incremental concentrations attributable to different hazard  
9 standards, and as such, it requires estimates of lead concentrations for all relevant  
10 environmental media, rather than only focusing on lead concentrations on floors and  
11 window sills. To account for the variability in lead concentrations in other environmental  
12 media in the U.S., the approach will apply Monte Carlo sampling of distributions of  
13 background lead. To simplify the approach, it is assumed that environmental media  
14 concentrations will not change with time.
- 15 • *Estimate exposure concentrations.* Exposure concentrations are estimated by combining  
16 information about the lead concentrations in different environmental media with  
17 information about where the populations of interest are located at different times, what  
18 activities they are engaged in, and other information about their behavior. Children under  
19 age 6 were selected for this approach because they are the focus of the residential RRP  
20 rule and are considered to be the most susceptible population for IQ effects resulting from  
21 lead exposure. Adults were selected to allow consideration of non-IQ-related effects  
22 from lead exposure, such as hypertension. .

23 Distributions of exposure variables for these populations are selected to roughly represent  
24 the range of exposures experienced in the U.S. by children under age 6 and adults.  
25 Therefore, environmental media concentrations are assumed to remain constant with  
26 time, while estimated exposure concentrations will change with children’s ages to reflect  
27 behavior differences in development.

28 The temporal patterns of exposure concentrations for children under age 6 will be  
29 developed using different exposure scenario variables for each year (0-1, 1-2, etc.). For  
30 adults, the temporal patterns will be developed using different exposure variables for  
31 each age range, which will be determined based on an analysis of adult activity patterns.  
32 These exposure variables will be defined by distributions and Monte Carlo sampling will  
33 be applied to select values from these distributions. Distributions of the exposure  
34 variables related to human activity (i.e., where they spend time and how long they spend  
35 in each location) are developed by analyzing human activity data from the Consolidated  
36 Human Activity Database (CHAD) (USEPA 2009b). Distributions of other exposure  
37 parameters (e.g., soil/dust ingestion rate, water ingestion rate) are developed by analyzing  
38 data included in EPA’s Child-Specific Exposure Factors Handbook (USEPA 2008b). For  
39 both populations, each age (for children under age 6) or age group (for adults) will be  
40 simulated separately to develop distributions of exposure concentrations for that age/age  
41 range, and the resulting distributions of lead exposure concentrations for all modeled  
42 ages/age ranges will serve as inputs to the blood lead modeling.

43 In the third step of the approach, *Estimate Blood Lead Concentrations*, the distributions of  
44 exposure concentrations will be used to estimate a distribution of blood lead concentrations for

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1 each population associated with a candidate hazard standard. As discussed further below, for  
2 children under age 6, blood lead concentrations will be estimated using EPA’s Integrated  
3 Exposure Uptake Biokinetic Model for Lead in Children (IEUBK). For adults, blood lead  
4 concentrations will be estimated using the International Commission for Radiation Protection’s  
5 Age-specific Biokinetic Model for Lead (the Leggett model), which, unlike the IEUBK, is  
6 capable of being used for estimating blood lead levels in adults.

7 After sufficient Monte Carlo samples have been simulated to develop a stable distribution of  
8 blood lead concentrations for each population, the estimated percentile of blood lead  
9 concentrations will be compared to the target blood lead level. If the estimate does not match the  
10 target (within the specified tolerance), a different candidate hazard standard for floor dust will be  
11 selected and the remaining steps of the approach will be repeated. This process continues until  
12 candidate hazard standards for floor dust and window sill dust have been developed for each  
13 population and potential level of concern.

14 The subsequent sections of this document provide more detailed descriptions of the approach for  
15 commercial and public buildings (Sections 2 through 5) and present the key data needs for  
16 consideration prior to implementing the approach (Section 6).

1 **2. Target Blood Lead Concentration**

2 **2.1. Selection of Endpoints**

3 In addition to a general hazard standard for public and commercial buildings, EPA is considering  
4 deriving an “adult hazard standard” for public and commercial buildings unlikely to be visited by  
5 children. Therefore, both children under age 6 and adults are considered in the target endpoint  
6 selection.

7  
8 **2.1.1. Children under age 6**

9 There is a strong consensus within the public health community that the adverse effects of lead  
10 exposure are greatest in children and that impairment of neurological development is the “critical  
11 effect” (the effect occurring at the lowest exposure levels) (USEPA 2006, CDC 2005, 2009a,  
12 Bellinger 2008, Lanphear et al. 2005). The intelligence quotient (IQ) is the most commonly  
13 measured neurodevelopmental endpoint in lead-exposed children, and blood lead is the most  
14 common exposure/dose metric in epidemiological studies. A number of recent studies (Canfield  
15 et al. 2003, Chiodo et al. 2004, Jusko et al. 2008, Lanphear et al. 2005, Miranda et al. 2007,  
16 Surkan et al. 2007, Téllez-Rojo et al. 2006) have reported decrements in IQ and other adverse  
17 effects at blood lead levels less than 10 µg/dL. It is generally agreed that no specific “threshold”  
18 blood lead level for adverse effects on IQ in children has been identified. In addition to IQ  
19 measures, there is rapidly accumulating evidence that lead also affects other aspects of  
20 neurological development, and that in many of these studies, these effects were also observed in  
21 children at blood lead levels less than 10 µg/dL. These studies are reviewed in USEPA (2006);  
22 more recent reports include an association between early lead exposure and increased incidence  
23 of ADHD (Nigg et al. 2008, 2010), ADHD coupled with other behavior problems (Roy et al.  
24 2008), as well as additional observations of increased criminal behavior (Wright et al. 2008) and  
25 other behavioral problems in young children (Chen et al. 2007).

26 Although there are some uncertainties in using both blood lead as a measure of exposure and IQ  
27 changes as an outcome measure, it is more difficult to generalize the results of the more complex  
28 neurobehavioral effects identified above. Therefore, children’s IQ has been chosen as the  
29 primary critical endpoint for determining the potential blood lead levels of concern. In making  
30 this choice, it is recognized that IQ effects do not capture the entire spectrum of adverse  
31 neurological effects associated with lead exposure in children. Estimating decrements in IQ thus  
32 represents a lower bound on the overall adverse effects of lead exposures to children.

33  
34 **2.1.2. Adults**

35 While adult lead exposures are known to be associated with a range of adverse effects, (USEPA  
36 2006), the best documented endpoints, and those that have been found to occur in populations  
37 with relatively low body burdens, are effects on the cardiovascular system. Increases in blood  
38 pressure levels or hypertension is a risk factor for various cardiovascular diseases. A large  
39 number of studies have found blood lead concentrations to be associated with varying degrees of  
40 blood pressure elevation in adults. A large meta-analysis of 31 U.S. and European studies of  
41 over 54,000 subjects (Nawrot et al. 2002) found a statistically significant relationship between  
42 blood lead levels and both systolic and diastolic blood pressure. The study found that a doubling

1 of blood lead concentration was on average associated with a 1.0 mm Hg increase in systolic  
2 blood pressure (95 percent confidence limits 0.5 – 1.4 mm Hg) and a 0.6 mm Hg increase in  
3 diastolic blood pressure (95 percent confidence limits 0.4 – 0.8 mm Hg). Many of the studies  
4 reviewed by Nawrot et al. (2002) included substantial proportions of subjects with blood lead  
5 levels less than 10 ug/dL and no evidence of a threshold for blood pressure effects was found in  
6 an accompanying regression analysis of these data. In addition, a more recent review of the  
7 blood lead-blood pressure/cardiovascular disease data (Navas-Acien et al. 2007) similarly  
8 concluded that there is a modest relationship between blood lead concentrations and  
9 hypertension, and that there appears to be no threshold for these effects. Similar results have  
10 been reported in various populations, including menopausal and perimenopausal women (Nash et  
11 al. 2003), workers (Weaver et al. 2008), and individuals with different ALAD genotypes  
12 (Scinicariello et al. 2010).

13 Although several studies have evaluated a variety of possible cardiovascular effects associated  
14 with blood lead (including coronary artery disease, angina pectoris, acute myocardial infarction,  
15 heart rhythm abnormalities, stroke, peripheral artery disease, and mortality from cardiovascular  
16 disease and stroke; see reviews in USEPA 2006, Navas-Acien et al. 2007), the particular effect  
17 that is likely to arise from elevated blood pressure remains uncertain. Therefore, blood pressure  
18 has been chosen as the endpoint for determining the potential blood lead levels of concern in  
19 adults.

20

## 21 **2.2. Selection of Target Blood Lead Concentrations**

### 22 **2.2.1. Children under age 6**

23 For purposes of this Approach, a distribution for a hypothetical child will be modeled around  
24 individual candidate hazard standards. Blood lead levels of 1, 2.5 and 5 µg/dL have been chosen  
25 in order to evaluate a range of potential hazard standards. These levels were chosen, in part,  
26 based on recent literature which shows that increases in children’s blood lead from 1 to 10 µg/dL  
27 result in a greater decrement in IQ score than increases from 10 to 20 µg/dL, or from 20 to 30  
28 µg/dL (Lanphear et al. 2005; Canfield et al. 2003; Schwartz 1994). This finding indicates a  
29 steeper dose-response relationship at blood lead levels less than 10 µg/dL.

30 Several different models relating various blood lead metrics (lifetime, concurrent, peak and early  
31 childhood) to IQ test results were reported in Lanphear et al. (2005). These models predicted a  
32 wide range of IQ changes for given blood lead concentrations. Log-linear models relating IQ  
33 changes to all blood lead metrics were developed and indicated that the relationships between IQ  
34 change and blood lead are curved, with steeper slopes at low blood lead levels. They also fit  
35 piecewise models (consisting of separate linear fits for different blood lead concentration ranges)  
36 to several of the blood lead metrics. The report presented the results developed for the  
37 concurrent blood lead metric, but EPA (U.S.EPA Activity-related Communication 2007) also  
38 obtained the relevant piecewise models for lifetime average blood lead concentrations based on  
39 the same data set.

40 For the blood lead metric, this approach is considering using both the lifetime and concurrent  
41 blood lead metrics. The peak blood lead metric was considered for this approach but ultimately  
42 not selected given the exposure scenario under consideration, which involved a relatively low-  
43 level, chronic exposure for the duration of the exposure period. Given that the approach does not

1 include time-varying media concentrations, concurrent blood lead measures could be preferred  
2 because they would involve calculating an average for ages 5 or 6 years, which might result in  
3 higher blood lead levels than the lifetime average because it would allow for maximum  
4 accumulation of lead in the body. On the other hand, exposures are likely to be highest during  
5 the first two years of life, based on behavior patterns and amount of time spent in the residence,  
6 and as a result the lifetime average could be higher than the concurrent concentration. For this  
7 approach, it is proposed that both metrics be calculated for each candidate hazard standard and  
8 that the metric resulting in the overall higher blood lead level be selected to provide a basis for  
9 standards presentation.

10 **2.2.2. Adults**

11 This approach will use available blood lead-blood pressure relationships to select potential blood  
12 lead levels for consideration for the hazard standard for adults in public and commercial  
13 buildings. These levels have been selected in a manner consistent with that used to select the  
14 levels considered for children under age 6; that is, the available epidemiological data have been  
15 used to determine a lower-end range of adverse effects and several blood lead levels covering  
16 this range. Blood lead levels of 0.3, 1, 5, 10 and 20 µg/dL were chosen to evaluate a range of  
17 potential hazard standards using the Nawrot et al (2002) meta-analysis, which reported a two-  
18 fold increase in blood lead concentration associated with a 1.0 mm Hg rise in systolic pressure  
19 and a 0.6 mm Hg increase in diastolic pressure. These blood lead levels were chosen based on  
20 the range of average blood lead levels represented in the studies included in the meta analysis. A  
21 careful review of recent studies will be performed to ensure that there are no major new  
22 findings that call the general results of that study into question, and sensitivity analyses can be  
23 used to derive defensible lower- and upper-bound risk estimates based on the Nawrot et al.  
24 (2002) statistical confidence limit estimates.

25

26

1 **3. Environmental Media and Exposure Concentrations**

2 Lead exposures are characterized in this approach by combining environmental media  
3 concentrations with exposure variable data (e.g., human activity data, ingestion rates, respiration  
4 rates). Distributions of environmental media concentrations are developed from the available  
5 literature for all microenvironments expected to contribute to lead exposures (e.g., floor dust,  
6 soil, air). These distributions are sampled using Monte Carlo techniques, the lead dust loadings  
7 are converted to lead dust concentrations (Appendix A), and the environmental media  
8 concentrations for the microenvironments are time-weight averaged using the activity pattern  
9 information and combined with other exposure variable data to estimate exposure concentrations.  
10 This process is described in detail below.

11 **3.1. Estimating Distributions of Concentrations in Each Microenvironment**

12 For each microenvironment of interest, distributions of dust lead concentrations, soil lead  
13 concentrations, and air lead concentrations are required as inputs to the blood lead model. Each  
14 distribution will account for the expected variability of lead concentrations in the medium and  
15 should be nationally representative to the extent possible. Floor and window sill dust  
16 concentrations must be characterized separately because they are fixed based on the candidate  
17 hazard standards being evaluated. Table 3-1 shows for the public and commercial hazard  
18 standard approach which media concentrations are needed in each microenvironment category.  
19 The assumption is made that while in a car, a child or adult is not coming into contact with lead  
20 in dust or soil. In addition, exposure to soil is only included when the child or adult is outdoors;  
21 soil is tracked into the indoor environment, but is accounted for as part of indoor dust; and the  
22 dust concentrations will be specifically developed to account for the tracked-in soil.

23 A literature search will be conducted to identify candidate data sources to represent each medium  
24 and microenvironment. Where possible, microenvironment categories will be divided according  
25 to particular lead exposure and the characteristics of children’s activities in the  
26 microenvironments. However, if specific data are not available, microenvironments within a  
27 category will be combined to assure adequate data coverage. The available data will be  
28 examined and an appropriate distribution will be developed based on this information for each  
29 medium/microenvironment combination. In general, candidate distributions will be the normal  
30 distribution, the lognormal distribution, or the uniform distribution. Previous similar  
31 assessments (e.g., USEPA 2008c) have used the fact that many media concentration distributions  
32 are positively skewed and the lognormal distribution often is the most appropriate representative.  
33 The definition of each distribution will be an arithmetic mean and standard deviation (for normal  
34 distributions), a geometric mean and geometric standard deviation (for lognormal distributions),  
35 or a lower and upper cutoff (for uniform distributions).

36

**Table 3-1. Media Concentration Distributions Needed for the Commercial and Public Building Hazard Standard Approach**

| Microenviron-ment Type       | Dust Conc., Floors   | Dust Conc., Window Sills  | Soil Conc.                        | Air Conc.  |
|------------------------------|--|---|-----------------------------------|--|
| Residence                    | Representative dust concentration (converted from dust loading if necessary) | Representative dust concentration (converted from dust loading if necessary)  | Not needed                        | Representative indoor air concentration  |
| Commercial/ Public Buildings | The candidate floor hazard standard loading, converted to concentration      | The candidate window sill hazard standard loading, converted to concentration | Not needed                        | Representative indoor air concentration  |
| Child-Occupied Facilities    | Representative dust concentration (converted from dust loading if necessary) | Representative dust concentration (converted from dust loading if necessary)  | Not needed                        | Representative indoor air concentration  |
| Outdoors                     | Not needed   | Not needed  | Representative soil concentration | Representative ambient air concentration   |
| Traveling                    | Not needed   | Not needed  | Not needed                        | Representative in- vehicle concentration compatible with near-roadway conditions |

1

2 **3.2. Estimating Media Concentrations from Distributions**

3 After the distributions have been defined, they will be used in an exposure model that utilizes  
 4 Monte Carlo sampling techniques to characterize the variability in exposures. Specifically, each  
 5 media concentration distribution will be sampled to estimate the total lead exposure of a  
 6 hypothetical person (referred to as a Monte Carlo “realization”). This process will be repeated  
 7 across numerous realizations, each modeling different hypothetical people, to develop a  
 8 distribution of lead exposure concentrations across the set of hypothetical people. The amount of  
 9 time each of these hypothetical people spends in each microenvironment will be consistent with  
 10 the activity patterns described in Section 3.4.1. The media concentrations for each  
 11 microenvironment used for each hypothetical person will be sampled from the distributions,  
 12 which results in each hypothetical person having an individualized set of environmental media  
 13 concentrations.

14 The first step in estimating the environmental media concentrations is selecting the candidate  
 15 hazard standards for floors and window sills in the public/commercial building. The candidate  
 16 floor dust hazard standard is selected first and then the accompanying window sill candidate  
 17 standard is estimated using a relationship between floor dust lead and window sill dust lead  
 18 developed from empirical data. Because the floor and window sill loadings in a building are  
 19 expected to be correlated and because the hazard standard implementation will assume that both  
 20 hazard standards are being met simultaneously in a building, it is necessary to fix the candidate  
 21 floor and window sill hazard standards simultaneously. Several data sets exist which could be

1 used to derive an empirical relationship between the floor and window sill loadings, and these  
2 are discussed in Section 6.1.4.

3 Once the candidate hazard standards have been fixed, a set of Monte Carlo realizations will be  
4 simulated to capture the variability in environmental concentrations in the other exposure media.  
5 For each hypothetical child, pseudo-random numbers (referred to as “seeds”) will be generated  
6 for each of the environmental media in Table 3-1. These seeds will be used to sample from the  
7 underlying distributions to generate the estimate of environmental media concentrations in each  
8 microenvironment for that realization. The only media concentrations that will not be sampled  
9 from the relevant distributions are public/commercial floor and window sill, which are fixed  
10 based on the candidate hazard standards being evaluated.

11 The activity patterns change with age, as described in Section 3.4. However, the assumption is  
12 made that the media concentrations in each microenvironment do not change significantly  
13 through time and that the type of microenvironment within each microenvironment category that  
14 the modeled individual visits does not change. Thus, the media concentrations are sampled once  
15 for each hypothetical individual and these samples are used for all ages of the individual’s life.  
16 For example, a child may spend more time in the car at age 5 than at age 1, but the  
17 environmental lead concentration to which that child is exposed while in the car (but not  
18 necessarily the child’s lead exposure, which is affected by such exposure factors as breathing  
19 rate) is assumed the same for both ages.

20 Media concentrations are needed to estimate exposures for both adults and children. The activity  
21 patterns are different for these two cohorts; however, the residential, outdoor, and vehicle  
22 environmental concentration distributions are similar for adults and children. Thus, the same  
23 realizations of media concentrations are used for adults and for children. Note, however, that  
24 because the sojourn time in each microenvironment is different, the *exposure* concentration will  
25 not be the same across children and adults for each realization.

### 26 **3.3. Converting Dust Lead Loading to Dust Lead Concentration**

27 Each candidate hazard standard will be developed in terms of lead dust loading on the floor and  
28 window sill, in units of lead mass per unit area. In addition, many lead exposure data in the  
29 literature are reported as lead loadings based on the total amount of lead mass collected in wipe  
30 or vacuum samples in a home. The blood lead models considered for this approach (discussed in  
31 Section 4), however, do not accept lead dust loadings as inputs. Instead, they require lead dust  
32 exposures to be in units of lead concentration (mass of lead per mass of dust). Thus, a method is  
33 needed to convert between the two in the development of the floor and window sill hazard  
34 standards. This analysis will consider two methods, developed specifically for the hazard  
35 standard estimation, to convert from lead dust loading to lead dust concentration: a statistical  
36 regression model and a mechanistic mass-balance model. An overview, including the strengths  
37 and weaknesses of each method, is provided in this section, and full details are provided for each  
38 in Appendix A.

39 The first method involves deriving a statistical relationship between observed lead dust loadings  
40 and lead dust concentrations in a nationally representative dataset. The HUD survey of lead in  
41 homes (USEPA 1995) contains average floor lead loadings from both wipe and vacuum samples  
42 as well as floor lead concentrations at approximately 280 homes. The survey was designed to be  
43 nationally representative and covers homes in four different vintage categories: Pre-1940, 1940-  
44 1959, 1960-1979, and Post-1980. Only the first three vintages are expected to include homes

1 with lead-containing paint because in 1978 lead was restricted in residential paint by law. In  
2 order to focus on the relationship in homes with lead paint, data from the earlier three vintages  
3 were combined and a regression equation was developed to describe the relationship between  
4 lead loading and lead concentration. Because wipe samples tend to capture more of the existing  
5 lead dust and are not subject to vacuum collection inefficiencies, the wipe loading data were used  
6 to develop the relationship. In addition, both a linear regression and a regression between the  
7 natural log-transformed variables were performed, and the log-transformed data were more  
8 completely explained by their regression coefficient (see Appendix A for more details). The  
9 final relationship between lead loading and lead concentration based on these data is:

10 
$$Concen = 50.96 \times Loading^{0.6553}$$

11 The HUD data also contain information about the window sill dust loadings, but no window sill  
12 concentration information is available. Window sill loadings and concentrations are available  
13 from a Rochester, NY study (Lanphear et al. 1998a), and could be used to develop a regression  
14 equation for window sills. Unlike the HUD data, however, these data may not be representative  
15 of relationships between loadings and concentrations across the U.S., and they may introduce  
16 bias when compared with the HUD data.

17 These data are from residences and may not reflect the relationship between floor loadings and  
18 concentrations in public/commercial buildings. To date, no dataset has been located which could  
19 accurately define the empirical relationship in public/commercial buildings, so the residential  
20 data are used as a surrogate. However, this will necessarily introduce uncertainty into the  
21 calculations.

22 In addition to this regression equation, a mechanistic mass-balance model was developed. This  
23 model accounts for the three dominant sources of lead to indoor dust: penetration of ambient air  
24 into the indoor environment, tracking of lead soil into the building, and flaking of lead-  
25 containing paint from walls. Removal occurs due to ventilation and routine cleaning. The model  
26 preserves the total mass in the system and accounts for the accumulation of both lead and  
27 particulate on the floor and in the indoor air. The particulate must be included in the model in  
28 order to calculate the lead dust concentration because the denominator of the concentration is  
29 total dust mass. Thus, in addition to the lead sources, there is also an indoor source of mass from  
30 cooking, smoking, and human dander that contributes to dust but is not expected to contain  
31 appreciable concentrations of lead. By converting the mass-balance differential equations to  
32 difference equations, the model can be integrated forward in time. For the hazard standard  
33 calculation, however, the dust levels are expected to be relatively constant in time and not to be  
34 subject to any short-term perturbations, such as renovation activities. Thus, the model equations  
35 can be solved directly for the steady-state solutions. These solutions provide total dust mass and  
36 total lead mass, and from these both the loading and concentration can be calculated. Thus, the  
37 steady-state solutions can be used to derive the slope in the equation:

38 
$$Concen = \frac{1}{Slope} \times Loading$$

39 This slope is then given by (also derived as equation 3 in Appendix A):

$$slope = \frac{1}{[(R + CE \times CF)(AER + D) - RD] \times V \times FloorLoading} \times$$

$$[CoverageDens \times ChipFraction \times V \times WallLoading \times UnitConv \times (AER + D) +$$

$$TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} \times (AER + D) +$$

$$PartAir \times D \times AER \times P \times V +$$

$$D \times (CookingRate + SmokingRate + DanderRate)]$$

Where:

*AER* = air exchange rate (hour<sup>-1</sup>)

*P* = penetration efficiency (unitless)

*V* = volume of the house (m<sup>3</sup>)

*D* = deposition rate (h<sup>-1</sup>)

*R* = resuspension rate (h<sup>-1</sup>)

*PbPaintConcen* = lead concentration in the paint (mg/cm<sup>2</sup>)

*ChipFraction* = fraction of total wall area which flakes from the walls per year (year<sup>-1</sup>)

*WallLoading* = area of wall space per unit volume of the building (m<sup>2</sup>/m<sup>3</sup>)

*CoverageDens* = the coverage density of paint on the wall (g/m<sup>2</sup>)

*UnitConv* = unit conversion necessary to make units consistent 1 year/8760 h)

*PbSoilConcen* = concentration of lead in the tracked-in soil (µg/g)

*TrackingRate* = rate at which particulate is deposited on front mats (g/h)

*MatFrac* = fraction of total tracked material which is deposited on the front mat (as opposed to the remainder of the building) (unitless)

*CE* = cleaning efficiency (unitless)

*CF* = cleaning frequency (cleanings/h)

*PartAIR* = concentration of particulate in ambient air (g/m<sup>3</sup>)

*CookingRate<sub>Part</sub>* = rate of generation of particulate mass due to cooking (g/h)

*SmokingRate<sub>Part</sub>* = rate of generation of particulate mass due to smoking (g/h)

*DanderRate<sub>Part</sub>* = rate of generation of particulate mass due to dander (g/h)

In this equation, most variables are set to their central tendency value when converting the loadings to concentrations. However, the slope is particularly sensitive to the cleaning

1 frequency, building volume, and outdoor soil tracking rate, and distributions are available in the  
2 literature for each of these variables. Thus, for each hypothetical person in the Monte Carlo  
3 simulation, each of these three variables will be sampled using a pseudo-random number and the  
4 resulting slope will be calculated. Then the hazard standard will be converted from a loading to  
5 a concentration using the combination of inputs for that person.

6 At present, the mechanistic model only describes the floor loading-to-concentration relationship  
7 and does not model the accumulation of lead and dust on window sills. The processes governing  
8 such accumulation are not as well understood. The model could be extended, however, so that a  
9 separate slope could be developed for the window sill conversion.

10 Each of these two alternative conversion methods has strengths and limitations. The regression  
11 equation is based on a nationally-representative dataset with sufficient samples across different  
12 housing vintages, outdoor soil concentrations, and indoor paint concentrations. The regression  
13 equation has highest reliability for the range of loadings and concentrations in the original  
14 dataset, and the hazard standard is expected to fall within that range. The equation is specific to  
15 residences, however, and it cannot be easily extended to public and commercial buildings. In  
16 addition, the regression equation does not allow any incorporation of variability due to the  
17 difference in physical attributes and cleaning patterns among buildings. The underlying data  
18 show a wide spread across the loading-concentration parameter space, indicating wide house-to-  
19 house variability (see Appendix A).

20 The mechanistic model, on the other hand, allows for extension of the model to public and  
21 commercial buildings, provided the physical processes are described adequately and the proper  
22 input values can be developed. Because public and commercial buildings tend to be larger, more  
23 people come in and out of the buildings daily (thus introducing more dander to the indoor  
24 environment and diluting the indoor dust) and the cleaning patterns are different. Thus, these  
25 buildings can be expected to have a very different loading-to-concentration relationship from  
26 houses. The model, however, assumes that the indoor environment is well-mixed and contains  
27 no concentration gradients; thus, it can be applied to any portion of the public or commercial  
28 building where this assumption is valid. The mechanistic model also allows for the loading-to-  
29 concentration conversion to incorporate house-to-house variability. The model is subject to  
30 uncertainty, however, because of the relatively simple form of the physical equations and the  
31 absence of information about some of the variable inputs. The model has been calibrated against  
32 the HUD dataset and then compared to one additional dataset (see Appendix A), and is expected  
33 to return reasonable estimates for the national population in the range of the hazard standard.  
34 There currently are no data supporting relationships, however, between window sill loadings and  
35 concentrations and unless such slopes are developed, the same slopes as those used for the floor  
36 dust would have to be used in developing the window sill hazard standard.

### 37 **3.4. Characterizing Exposure Variables**

#### 38 **3.4.1. Human activity patterns**

39 For the purposes of this approach, an exposure profile describes the amount of time spent by a  
40 simulated individual from the population of interest in various microenvironments during a one-  
41 year period. The time spent in various microenvironments is provided as an input to subsequent  
42 components of the conceptual model presented here to determine the uptake of lead and  
43 associated health impacts. A collection of profiles represents a random sample drawn from the  
44 target population and it is intended that the statistical properties of the collection of profiles

1 approximate the statistical properties of the target population (in this case, U.S. children under  
2 age 6 and all U.S. adults). The simulated individuals spend varying amounts of time in different  
3 microenvironments, each with different distributions of lead concentrations, and this approach  
4 allows for the characterization of the resulting differences in lead uptake and the associated  
5 health impacts.

6 **3.4.1.1. Populations of interest**

7 Children under age 6 were selected as a target population for developing commercial and public  
8 building hazard standards because they are the population considered most susceptible to adverse  
9 health effects from exposure to lead-containing dust in residences. This choice is consistent with  
10 studies performed by EPA in support of the RRP rule for residential buildings (USEPA 2008c).  
11 In order to capture the variability in time spent in commercial and public buildings by children of  
12 various ages under age 6, this population is further divided into six, one-year age groups (0-1, 1-  
13 2, etc.) for the purposes of estimating exposure concentrations (see Section 3.5).

14 In addition to children under age 6, the approach for commercial and public buildings includes  
15 consideration of adverse health effects in adults. As a result, U.S. adults were also selected as a  
16 target population. To accommodate variations in exposures with changes in the amount of time  
17 spent in various microenvironments as adults age, this population will be further divided into age  
18 groups based on expected changes in activity patterns with age.

19 **3.4.1.2. Developing exposure profiles**

20 Exposure profiles will be developed using data from CHAD (USEPA 2009b) for the target  
21 population and algorithms from the APEX model. Developed by the EPA's National Exposure  
22 Research Laboratory, CHAD contains data collected from several studies designed to capture  
23 human activity patterns, and consists of one or more diaries of activities of each participant  
24 during the 24-hour period. It is commonly used in exposure assessment and provides required  
25 inputs to several EPA exposure models, such as HAPEM, SHEDS, and APEX<sup>1</sup>. Some  
26 applications of CHAD data in exposure assessments by EPA include the characterization of  
27 inhalation exposures in EPA's National Air Toxics Assessment (NATA) and numerous reviews  
28 of the National Ambient Air Quality Standards (NAAQS) for criteria pollutants. Among the  
29 various datasets available in CHAD, only the National Human Activity Pattern Study (NHAPS)  
30 dataset contains data from a nationally-representative sample. This study, sponsored by the EPA  
31 and conducted by the University of Maryland, contains responses from 9,386 participants  
32 collected between October 1992 and September 1994. Because it is deemed that NHAPS data  
33 may not be sufficient to generate large enough sample of exposure profiles, other studies will  
34 also be included to develop activity patterns of simulated individuals. These other studies  
35 contain data that is collected from the following specific geographic locations: Cincinnati, Ohio;  
36 Baltimore, Maryland; California children study; California adults and youth study; Denver,  
37 Colorado; Los Angeles, California; Valdez, Alaska; and Washington, DC.

38

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<sup>1</sup> HAPEM = Hazardous Air Pollutant Exposure Model; SHEDS = Stochastic Human Exposure and Dose Simulation Model; APEX = Air Pollutants Exposure Model.

1 To generate the activity pattern of a simulated individual for a one-year period, one needs to  
2 develop a composite diary of one year from individual 24-hour diaries. A simple approach is to  
3 assume that the individual engages in same set of activities and spends same amount of time for  
4 an entire period characterized by a CHAD diary. For example, a randomly sampled weekday  
5 diary from CHAD data can be assumed to be applicable for all weekdays for a simulated  
6 individual. While this approach may capture between-person variability in activity patterns in  
7 the target populations, the variation in day-to-day activities of the simulated individual is not  
8 modeled. Consequently this approach may result in unrealistically large or small exposure times.  
9 Therefore, a probabilistic algorithm that can also capture day-to-day variation in the activity  
10 patterns of simulated individuals needs to be applied to develop composite diaries from  
11 individual 24-hour diaries.

12 The Air Pollution Exposure Model (APEX) is a peer-reviewed EPA model that is used to assess  
13 inhalation exposure for criteria and toxic air pollutants. The APEX model currently incorporates  
14 two stochastic methods to develop composite diaries to evaluate inhalation exposure. The  
15 diversity-autocorrelation algorithm assembles multi-day diaries based on reproducing realistic  
16 variability in a user-selected key diary variable – the variable that is assumed to have dominant  
17 influence on exposure. This algorithm works by first creating diary pools from the CHAD data.  
18 A diary pool is a group of CHAD diaries that has a common diary variable that has significant  
19 effect on activity patterns. For example, diary pools can be created for each day type (weekday,  
20 weekend day) and season (summer, non-summer) because it is expected that the activities of a  
21 target population significantly differ from weekday to weekend and between a summer day and a  
22 non-summer day. Once diary pools are created, each diary in the pool is assigned a rank, or “x-  
23 score,” based on the key activity variable. The composite diary is then assembled based on the  
24 x-scores using the longitudinal diary assembly algorithm. This algorithm aims to reproduce the  
25 user-supplied statistics **D** and **A**. The **D** statistic quantifies the relative importance of within-  
26 person and between-person variances in the key activity variable. The **A** statistic quantifies the  
27 day-to-day autocorrelation, which characterizes the similarity in diaries from day to day.  
28 Additional details of this algorithm are presented in the APEX technical support document  
29 (USEPA 2008d).

30 The second algorithm, the Cluster-Markov algorithm, also stochastically generates composite  
31 diaries from individual 24-hour period diaries. This approach was developed to better represent  
32 variability in activity patterns among simulated individuals. This algorithm first groups the  
33 CHAD diaries into two or three groups of similar patterns for each of the 30 combinations of day  
34 type (summer-weekday, non-summer weekday and weekend), demographic group (males and  
35 females), and age group (0-4, 5-11, 12-17, 18-64, 65+). Next, for each combination of day type  
36 and demographic group, category-to-category transition probabilities are defined by the relative  
37 frequencies of each second-day category associated with each given first-day category where the  
38 same individual was observed for two consecutive days. A composite diary of one year is  
39 constructed by first randomly selecting one daily activity pattern from each of the CHAD  
40 categories to represent that particular day type and demographic group. Finally, a sequence of  
41 daily activities for a one-year period is generated as a one-stage Markov chain process using the  
42 category-to-category transition probabilities.

43 To generate a sufficiently large number of profiles (on the order of a tens of thousands), this  
44 approach will apply both of the above algorithms and evaluate them for their statistical

1 properties. The algorithm that most adequately represents both the within-person and between-  
2 person variability will ultimately be applied to characterize the human activity patterns.

3 **3.4.1.3. Defining microenvironments of interest**

4 ***Children under age 6***

5 While the time spent by children under age 6 in commercial and public buildings is of primary  
6 interest, their time spent in other microenvironments also contributes to overall lead uptake and  
7 therefore must be well characterized. In this approach, time spent by children under age 6 in the  
8 following microenvironments is estimated from CHAD data:

- 9 • Residences;
- 10 • Child-occupied facilities (COF);
- 11 • Outdoors;
- 12 • Traveling; and
- 13 • Public and commercial buildings.

14 It is assumed that the time spent in public and commercial buildings includes any time spent in  
15 an indoor building environment that is not a residential building or child-occupied facility, and is  
16 estimated from CHAD data by aggregating several location categories. The average, median,  
17 and 95<sup>th</sup> percentile of times spent in these microenvironments from CHAD data for the six  
18 children’s ages considered are presented in Table 3-2. Note that the CHAD data contain over  
19 100 location descriptions. For this approach, these locations were aggregated into the five  
20 categories mentioned above. For example, the time spent traveling includes general travel,  
21 motorized travel, travel by walking, and waiting for bus, train, or other vehicle. Similarly, time  
22 spent in other building includes time spent in public buildings (e.g., libraries, museums),  
23 hospitals, and commercial buildings (e.g., grocery stores, restaurants)<sup>2</sup>.

---

<sup>2</sup> This uses the CHAD terminology for “public” and “commercial”, as distinct from this proposal’s terminology, thereby breaking out “hospitals”.

1

**Table 3-2 Children’s Time Spent in Selected Microenvironments, by Age**

| Age   | Residence | COF  | Outdoor | Travel | Public/Commercial Buildings |
|---|-----------|------|---------|--------|-----------------------------|
| <b>Average time spent (Hours)</b>                       |           |      |         |        |                             |
| 0 - 1   | 21.32     | 0.45 | 0.51    | 0.81   | 0.81                        |
| 1 - 2   | 20.81     | 0.53 | 1.00    | 0.82   | 0.76                        |
| 2 - 3   | 19.96     | 0.73 | 1.4     | 0.95   | 0.84                        |
| 3 - 4   | 19.56     | 1.01 | 1.44    | 0.96   | 0.94                        |
| 4 - 5   | 18.96     | 1.38 | 1.66    | 0.92   | 0.99                        |
| 5 - 6   | 18.15     | 2.17 | 1.73    | 1.03   | 0.84                        |
| <b>Median time spent (Hours)</b>                        |           |      |         |        |                             |
| 0 - 1   | 22.00     | 0    | 0       | 0.67   | 0                           |
| 1 - 2   | 21.42     | 0    | 0.42    | 0.58   | 0                           |
| 2 - 3   | 20.50     | 0    | 0.67    | 0.67   | 0                           |
| 3 - 4   | 20.00     | 0    | 0.83    | 0.75   | 0                           |
| 4 - 5   | 19.25     | 0    | 1.00    | 0.75   | 0                           |
| 5 - 6   | 18.17     | 0    | 1.00    | 0.75   | 0                           |
| <b>95<sup>th</sup> percentile of time spent (Hours)</b> |           |      |         |        |                             |
| 0 - 1   | 24.00     | 2.71 | 2.50    | 2.42   | 3.91                        |
| 1 - 2   | 24.00     | 6.16 | 3.84    | 2.66   | 3.50                        |
| 2 - 3   | 24.00     | 7.83 | 5.25    | 2.83   | 3.41                        |
| 3 - 4   | 24.00     | 8.34 | 5.00    | 2.92   | 4.00                        |
| 4 - 5   | 24.00     | 8.75 | 5.68    | 2.41   | 3.96                        |
| 5 - 6   | 23.50     | 8.83 | 5.76    | 2.84   | 3.75                        |

2

3 **Adults**

4 As with children under age 6, adults’ time spent in commercial and public buildings is of  
 5 primary interest; however, their time spent in other microenvironments also contributes to  
 6 overall lead uptake and therefore must be well characterized. In this approach, time spent by  
 7 adults in the following microenvironments is estimated from CHAD data:

- 8 • Residences;
- 9 • Outdoors;
- 10 • Traveling; and
- 11 • Public and commercial buildings.

12 It is assumed that the time spent in public and commercial buildings includes any time spent in  
 13 an indoor building environment that is not a residential building, and is estimated from CHAD  
 14 data by aggregating several location categories. The average, median, and 95<sup>th</sup> percentile of  
 15 times spent in these microenvironments are presented in Table 3-3. These data are presented for

1 adults in five different age groups, which were developed by grouping ages with similar activity  
 2 patterns.

3

**Table 3-3. Adults’ Time Spent in Selected Microenvironments, by Age Group**

| Age   | Home   | Outdoor | Travel | Public/Commercial Buildings |
|---|--------|---------|--------|-----------------------------|
| <b>Average time spent (Hours)</b>                       |        |         |        |                             |
| 18 - 24   | 15.84  | 1.46    | 1.6    | 5.07                        |
| 24 - 30   | 15.62  | 1.3     | 1.58   | 5.45                        |
| 30 - 40   | 16.01  | 1.41    | 1.59   | 4.94                        |
| 40 - 60   | 16.26  | 1.39    | 1.58   | 4.73                        |
| 60 +  | 19.71  | 1.21    | 1.06   | 1.99                        |
| <b>Median time spent (Hours)</b>                        |        |         |        |                             |
| 18 - 24   | 15.22  | 0.3     | 1.2    | 5                           |
| 24 - 30   | 14.7   | 0.17    | 1.17   | 5.33                        |
| 30 - 40   | 15.08  | 0.27    | 1.18   | 4.18                        |
| 40 - 60   | 15.5   | 0.25    | 1.08   | 3.67                        |
| 60 +  | 20.5   | 0.17    | 0.58   | 0.92                        |
| <b>95<sup>th</sup> percentile of time spent (Hours)</b> |        |         |        |                             |
| 18 - 24   | 23.25  | 7.585   | 4.103  | 11.25                       |
| 24 - 30   | 23.381 | 7.613   | 4.381  | 12.25                       |
| 30 - 40   | 23.633 | 7.24    | 4.36   | 11.5                        |
| 40 - 60   | 23.75  | 7       | 4.667  | 11.417                      |
| 60 +  | 24     | 6.25    | 3.592  | 8.418                       |

4

5 **3.4.2. Other exposure variables**

6 Exposure variables other than the time spent in each microenvironment also affect the overall  
 7 exposure of a child or adult to lead. These characteristics or variables include the ingestion rate  
 8 of dust and soil, the intake rate of lead in the diet, the intake rate of lead in water, the ventilation  
 9 rate, the lead inhalation and ingestion absorption rates, and the maternal blood lead when the  
 10 child is born. In order to account for inter-individual variability in exposure in the target  
 11 populations, those exposure variables expected to have the highest sensitivity and to vary the  
 12 most strongly will be sampled from distributions. These include the ingestion of soil and dust by  
 13 age group, background water lead intake, and background diet lead intake. Distributions for the  
 14 ingestion of soil and dust will be generated from information in the Child-Specific Exposure  
 15 Factors Handbook (USEPA 2008b) and the Exposure Factors Handbook (USEPA 1997). To  
 16 estimate the distributions of lead dietary and water intake, the LifeLine Model (The LifeLine  
 17 Group 2008) will be used to estimate a distribution of intakes across the population by age (for  
 18 children under age 6) and age group (for adults). The ventilation rate and maternal blood lead

1 will not be sampled, but central tendency estimates will be taken in order to conserve  
2 computational resources; inhalation exposures are not anticipated to contribute in large measure  
3 to total lead exposure compared to soil and dust ingestion (USEPA, 2006) and the ventilation  
4 rate is not anticipated to be a sensitive variable. In addition, given the elimination rate of lead in  
5 children, maternal blood lead has only a minor impact on a child's blood lead levels beyond the  
6 age of six months with subsequent blood lead levels determined primarily by environmental  
7 exposures. For the absorption fractions, these variables may be sensitive in describing the  
8 child's overall response to lead exposure, but information in the literature is currently insufficient  
9 to derive distributions, so central tendency values will be used.

10 The sampled values for each variable differ across the different ages (for children under age 6)  
11 and age groups (for adults). To account for the potential correlations across ages, these variables  
12 will be sampled from age-specific distributions to ensure the same percentiles are used for each  
13 age/age group. For example, if a child has 90<sup>th</sup> percentile ingestion of soil and dust at age 1, they  
14 will also have 90<sup>th</sup> percentile ingestion of dust at age 5, and the actual ingestion values will be  
15 taken from the separate distributions for each age.

### 16 **3.5. Estimating Exposure Concentrations**

17 For each hypothetical person, the Monte Carlo sampling provides dust, soil, and air lead  
18 concentrations for each relevant microenvironment. The concentrations in each  
19 microenvironment must then be combined to provide overall air, soil, and dust concentrations for  
20 input into the blood lead model. First, the floor and window sill dust concentrations in each  
21 microenvironment are combined according to the equation:

$$22 \quad \text{dust} = \text{floor} \times \text{frac}_{\text{floor},t} + \text{sill} \times \text{frac}_{\text{sill},t}$$

23 where:

24  $\text{dust}$  = the average dust exposure concentration in that  
25 microenvironment

26  $\text{floor}$  = the concentration of lead in dust on the floor

27  $\text{frac}_{\text{floor},t}$  = fraction of dust exposure arising from floor dust for age  
28 range t

29  $\text{sill}$  = the concentration of lead in dust on the window sill

30  $\text{frac}_{\text{sill},t}$  = fraction of dust exposure arising from sill dust for age  
31 range t  
32

33 The  $\text{frac}_{\text{floor},t}$  variable will be adjusted for each age/age range to account for expected differences  
34 between infants, toddlers, preschoolers, kindergartners, and adults. Then, the concentrations for  
35 air, soil, and dust across microenvironments will be combined using the fraction of the time  
36 spent in each microenvironment for the specific age/age group. The following equation will be  
37 used:

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$$concen_{exp,t} = \frac{\sum_{i=1}^n (f_{i,t} \times concen_i)}{\sum_{i=1}^n f_{i,t}}$$

where:

- $concen_{exp,t}$  = the exposure concentration for age range t
- $f_{i,t}$  = fraction of time spent in each microenvironment for age range t
- $concen_i$  = the concentration in each microenvironment
- $n$  = the number of microenvironments in which exposure to the media occurs

In the case of air concentrations, the person is assumed to be exposed to air concentrations in all microenvironments. The person is assumed only to be exposed to dust, however, when indoors (either in the home or outside the home) but not when outdoors or in a vehicle. Similarly, the soil concentrations are only combined using the fractions of time in an outdoor microenvironment. A separate blood lead model input variable accounts for the total ingestion of dust and soil mass and the fraction of total dust+soil ingestion that arises from soil. Thus, provided that the dust and soil concentrations represent the average concentrations to which the person is expected to be exposed as a result of their activity pattern, the approach assumptions are compatible with the blood lead modeling assumptions.

1 **4. Estimation of Blood Lead Levels**

2 **4.1. Children under age 6**

3 **4.1.1. Overview of blood lead models for children**

4 A number of different approaches are available to estimate children’s blood lead levels in  
5 response to defined exposure scenarios (USEPA 2006). Approaches that have been implemented  
6 include explicit pharmacokinetic models (where the movement of lead is simulated through  
7 compartments with defined volumes and perfusion rates), biokinetic models (where lead moves  
8 from compartment to compartment based on first-order rate constants), and empirical models  
9 that predict blood lead as a simple regression-like function of steady-state exposure  
10 concentrations. In addition to these general-purpose models that take media concentrations or  
11 exposures as their inputs, there have been several studies (Rabinowitz et al. 1985, Lanphear  
12 2007) where the impacts of residential renovation activities on blood lead levels have been  
13 estimated directly for specific populations of children.

14 Among the available models, EPA’s IEUBK model (USEPA 2010a) is by far the most  
15 thoroughly tested and frequently used for assessment of the impacts of exposures in air, soil,  
16 house dust, diet and water on children’s blood lead concentrations. The IEUBK model was  
17 originally developed by EPA’s Office of Air Quality Planning and Standards (OAQPS) to  
18 support analyses of air quality standards starting in 1985. The model implements a biokinetic  
19 model developed by Harley and Kneip (1985) that predicts blood lead levels in children 0-7  
20 years old in response to specified lead exposures. In 1991, responsibility for further  
21 development of the IEUBK model was given to the Technical Review Workgroup (TRW),  
22 composed of representatives from several EPA program and regional offices. The model was  
23 released to the public in 1991 and has been updated continuously since then without basic  
24 changes to the model structure, although recommended default exposure factor and  
25 environmental concentration values have changed as new data have become available.

26 The EPA All Ages Lead Model (AALM), now under development, aims to extend beyond  
27 IEUBK capabilities to model external Pb exposure impacts (including over many years) on  
28 internal Pb distribution not only in young children, but also in older children, adolescents, young  
29 adults, and other adults well into older years (up to 90 years of age) (USEPA 2005). The AALM  
30 essentially uses adaptations of the IEUBK exposure module features, coupled with adaptations of  
31 IEUBK biokinetics components (for young children) and of the Leggett model’s biokinetics  
32 components (for older children and adults). The AALM has not yet undergone sufficient  
33 development and validation for it to be recommended for general risk assessment use.

34 EPA’s Clean Air Science Advisory Committee (CASAC) reviewed the use of the IEUBK in  
35 support of the 1990 revisions to the National Ambient Air Quality Standard (NAAQS) for lead,  
36 and the structure and parameter values in the model have also been reviewed by the Indoor Air  
37 Quality and Total Exposure Committee of the Science Advisory Board (SAB). The IEUBK has  
38 been subject to external peer review, its performance has been tested against a number of large  
39 data sets, and its predictions have been compared to competing pharmacokinetic and biokinetic  
40 models (NIEHS 1998, USEPA 2006). The IEUBK was the primary blood lead assessment  
41 model used in EPA’s risk assessment supporting the lead NAAQS revision (USEPA 2007).

42 The most plausible alternatives to the IEUBK include the “Leggett” biokinetic model (Leggett  
43 1993) and the pharmacodynamic model developed by O’Flaherty et al. (1993, 1995). The

1 Leggett model was developed with support from the International Agency for Radiological  
2 Protection (ICRP) to support risk assessment for radionuclides of lead and related elements. The  
3 model is technically sophisticated, simulating the transfer of lead among 15 compartments in the  
4 body, based on a large body of age-specific biokinetic data on lead and other metals. In addition,  
5 the default time step for biokinetic simulation is one day instead of the minimum one-month time  
6 step used in the IEUBK model, which suggests that the Leggett model might be better suited to  
7 modeling the impacts of short-term exposures. Despite these potential advantages, the Leggett  
8 model has not undergone the same degree of testing against environmental data sets as has the  
9 IEUBK. In addition, the Leggett model does not include a detailed exposure model like the  
10 IEUBK; and pathway-specific daily intakes must be specified by the user. Detailed comparisons  
11 of the IEUBK and Leggett model results indicate that, for plausible exposure scenarios and  
12 absorption fraction values, the Leggett model tends to predict higher children's lead uptake and  
13 blood lead levels than the IEUBK for similar exposures (USEPA 2006). One important feature  
14 of the Leggett model not shared by the IEUBK is that it has the capability to model blood lead  
15 overall from birth through adulthood.

16 The O'Flaherty pharmacodynamic model (O'Flaherty et al. 1993, 1995) is likewise more  
17 complex and technically sophisticated in some ways than the IEUBK model. As noted above, it  
18 is a truly pharmacodynamic model with lead transfer modeled between compartments with  
19 defined age-specific volumes and perfusion rates. In addition, the O'Flaherty model explicitly  
20 models the age-related changes in bone growth and deposition/deposition processes. Like the  
21 Leggett model, however, the O'Flaherty et al. model has not been subject to the same degree of  
22 calibration and testing against human data sets (particularly children) as has the IEUBK. As will  
23 be discussed below, in comparison studies, the O'Flaherty et al. and Leggett models tend to give  
24 similar blood lead predictions for defined adult exposure scenarios.

25 Empirical (regression-type) blood lead models based on environmental concentrations were not  
26 considered for use in this analysis because the available models (Lanphear et al. 1998b, Schwartz  
27 et al. 1998, USEPA 1998) predict steady-state blood lead levels in adults or children assumed to  
28 be facing constant exposures from soil, dust, and paint. They are thus poorly suited to estimating  
29 the impacts of variable exposures arising from renovation activities. Two studies were also  
30 identified (Rabinowitz et al. 1985, Lanphear et al. 2007) that directly estimated the potential  
31 impacts of residential renovation on children's blood lead levels. While these studies provide  
32 helpful support for the current analysis, neither is suited for exposure-response analysis since the  
33 number of exposed subjects is small in both studies and both were conducted in older urban  
34 neighborhoods where renovation hazards may not be typical of those in the rest of the U.S. The  
35 study by Rabito et al. (2007) was likewise limited to estimating the blood lead impacts of  
36 demolition activities in a high-lead area.

#### 37 **4.1.2. IEUBK**

38 Based on the evaluation described above, the IEUBK was selected for modeling blood lead  
39 concentrations for children under 6 years of age in the residential exposure scenario. The  
40 IEUBK model is a multicompartimental pharmacokinetics model that, in the default mode,  
41 provides estimates of long-term (annual average) blood lead levels in children (birth to 7 years).  
42 Used in batch mode, the IEUBK model can provide estimates of blood lead concentrations over  
43 shorter time intervals; run in batch mode, temporal resolution of one month can be achieved.  
44 That is, input variables can be specified and blood lead outputs can be obtained for each month  
45 of exposure. The exposure module simulates intake of lead for six exposure media: air, diet

1 (excluding drinking water), drinking water, outdoor soil/dust, indoor dust, and other. Input  
2 variables, including absorption fraction and inhalation rate, water intake, dietary intakes of  
3 specific food classes, and outdoor soil/dust and indoor dust ingestion rates, are user-specified.  
4 Age-specific lead inhalation uptakes are estimated for exposure to outdoor and indoor air, based  
5 on age-dependent estimates of time spent indoors and outdoors, estimates of indoor and outdoor  
6 air lead concentrations, and age-dependent inhalation rates. Additionally, a respiratory tract  
7 adsorption fraction is used to account for both deposition of inhaled lead in the respiratory tract  
8 and absorption of deposited lead from either the respiratory tract or from the gastrointestinal (GI)  
9 tract. The model also contains an option for calculating indoor dust lead concentrations based on  
10 an empirical relationship among air, outdoor soil/dust, and indoor dust lead levels. Ingestion  
11 uptake is calculated using absorption fractions that are specific to the ingested medium (diet,  
12 drinking water, outdoor soil/dust, or indoor dust).

13 Under the default option, total gastrointestinal (GI) lead uptake is modeled as being composed of  
14 a saturable and an unsaturable component using the IEUBK default parameters describing the  
15 relative importance of these two components as a function of total lead intake. The user may  
16 change the model inputs describing the saturable pathway, or turn it off completely. The outputs  
17 of the uptake module are estimates of the masses of lead absorbed into the body over time as a  
18 function of concentrations in the various exposure media.

19 In the biokinetic module of the IEUBK model, absorbed lead (from ingestion and inhalation) is  
20 assumed to appear immediately in the plasma-extracellular fluid (ECF) compartment. The  
21 plasma-ECF compartment constitutes the central compartment in the biokinetic model from  
22 which exchange to all other compartments occurs. Trabecular and cortical bone (which are not  
23 directly coupled in the IEUBK model) constitute the main long-term storage compartments, with  
24 the estimated turnover in other compartments being more rapid. The binding capacity of the red  
25 blood cell (RBC) compartment is modeled as being saturable, simulating the limited capacity of  
26 aminolevulinatase (ALAD) and other lead-binding proteins. Lead excretion occurs  
27 through a urine pathway (distinct from the kidney compartment). Hepatobiliary secretion is  
28 coupled with the liver compartment, with a minor component of excretion from “other soft  
29 tissues” (i.e., skin, hair, and nails). The sole output from the IEUBK model is blood lead  
30 concentrations for each exposure period; the model does not support the estimation of bone  
31 accumulation.

## 32 **4.2. Adults**

### 33 **4.2.1. Overview of blood lead models for adults**

34 The relative merits of the various models for predicting blood lead levels were discussed in  
35 Section 4.1. As noted there, the AALM has not yet undergone sufficient development or  
36 validation for it to be recommended for use in this approach. To the extent that the performance  
37 of the most well-documented adult blood lead models has been compared, the Leggett biokinetic  
38 model (Leggett 1993) and the O’Flaherty et al. (1993, 1995) pharmacokinetic model produce  
39 generally similar results for simple exposure scenarios. Both models, despite their differences in  
40 structure, include relatively sophisticated representations of lead transport in the body and both  
41 are capable of modeling short- and long-term exposures. The Leggett model has been chosen as  
42 the primary method for adult blood lead modeling in this approach for several reasons. First,  
43 development of the Leggett model built on a very large database of animal and human data  
44 relating to the behavior of lead and other metals in the body. In contrast, the O’Flaherty et al.

1 model is based primarily on animal (rodent) data, and its adaptation to predicting human blood  
2 lead levels relies heavily on allometric scaling. While the IEUBK has been subjected to much  
3 more testing and calibration than either the Leggett or O’Flaherty et al. models, among models  
4 that are capable of predicting adult blood lead, the Leggett model likewise has been much more  
5 thoroughly tested than the O’Flaherty et al. model. One important additional consideration is  
6 that, as part of previous analyses, OAQPS and OPPT have adapted the Leggett model for easy  
7 batch mode operation, which greatly facilitates the analyses of large numbers of exposure  
8 scenarios and sensitivity analyses of important variables.

#### 9 **4.2.2. Leggett model**

10 The Leggett model is capable of predicting changes in blood lead levels for exposed individuals  
11 over their entire lifespan (birth to 90 years old). The compartmental structure of the Leggett  
12 model was patterned after similar models developed by the ICRP to model the age-specific  
13 biokinetics of calcium-like radionuclides (Leggett 1993). In the biokinetic component of the  
14 Leggett model, the movement of absorbed lead (from ingestion and inhalation) through various  
15 body “compartments” is simulated. The model is “biokinetic,” rather than “pharmacokinetic,”  
16 because transfers between compartments are controlled by first-order transfer coefficients  
17 (equivalent to first-order rate constants), rather than being perfusion controlled. The values for  
18 the transfer rates were estimated using a range of values from adult human radioactive tracer  
19 studies, autopsy data from adults and children, and data from animal studies related to the  
20 absorption, deposition, and excretion of lead and chemically similar elements (Leggett 1993).  
21 Leggett developed estimates of biokinetic parameters for six age categories: newborn (0 to 100  
22 days), 1 year, 5 years, 10 years, 15 years, and 25 years and older, with age-specific transfer  
23 parameters for children estimated by interpolation between the nearest values. Transfer factors  
24 for children were adjusted to take into account the more rapid bone turnover (calcium/lead  
25 addition and resorption) in children compared with adults. The Leggett model does not accept  
26 exposure concentrations directly. Instead, it accepts total inhalation and ingestion intakes  
27 (administered doses) as inputs. Thus, the exposure concentration time series are converted to  
28 intakes using specified input values, as described in Table 6-3.

29 There are several options for defining the adult exposure period when modeling lead exposures  
30 associated with different hazard standards. For this approach, blood lead levels will be modeled  
31 starting at age 18 through age 80, with initial blood lead levels sampled from the distribution of  
32 blood lead levels for 18-year-olds from the most recent NHANES database.



1 **5. Application of the Model for Estimating Hazard Standards**

2 Sections 2 through 4 describe the methods used for calculating a person’s blood lead  
3 concentration distribution by specifying lead dust loadings for the dust and window sill candidate  
4 hazard standards and simulating numerous hypothetical individuals, each with different sampled  
5 behaviors and environmental media concentrations. The purpose of this model, however, is to  
6 calculate the floor and window sill dust lead loadings corresponding to the target blood lead  
7 levels, or solving for the input of the model with a known output. This section explains the  
8 methodology used for calculating dust lead loadings for the candidate hazard standards which  
9 result in a target blood lead level.

10 As described in Section 3, media concentrations and some exposure variables will be sampled  
11 probabilistically for all microenvironments except for the candidate commercial/public buildings  
12 hazard standards (floor and window sill) for each realization. Therefore, each realization will  
13 result in a different blood lead concentration, as each sampling will likely have unique set of  
14 media concentrations. The same distributions will be used for thousands of unique realizations  
15 to generate a distribution of blood lead concentrations associated with each set of candidate  
16 hazard standards.

17 Because the relationship between hazard standards and the various contributions to blood lead  
18 concentration does not exist as an equation in closed form, selecting a set of candidate hazard  
19 standards that result in a target blood lead concentration consists of two steps:

- 20 1. Create a response surface to correlate candidate dust and window sill lead dust loading  
21 levels with blood lead levels. The response surface will be constructed by running many  
22 iterations with different target loading levels, with a limited number of realizations for  
23 each iteration, to generate rough approximations of the corresponding blood lead levels.
- 24 2. Using this response surface, predict the target loading that corresponds to a prespecified  
25 point on the blood lead concentration distribution, and run the model to confirm/deny this  
26 prediction. Repeat iteratively until the loading value corresponding with the prespecified  
27 point has been precisely determined. This step will involve running fewer iterations with  
28 a much higher number of realizations, thus creating highly precise relationships between  
29 target loadings and blood-lead levels.

30 **5.1. Creating the Target Loading-to-Blood-Lead Response Surface**

31 Because multiple distributions are sampled for each realization, the resulting distributions of  
32 blood lead levels may have a wide range. Therefore, many realizations may need to be simulated  
33 in order for the blood lead distribution to become stable (i.e., adequately represent the underlying  
34 inputs). To minimize the number of iterations required to identify the candidate hazard standards  
35 corresponding to the prespecified blood lead concentration distribution point, a response surface  
36 will be created for a range of candidate hazard standards that will provide an educated guess as  
37 to what loading will correspond to a particular target blood lead percentile. Because the response  
38 surface will be used only to provide a preliminary estimate of final candidate loadings, fewer  
39 realizations can be conducted with each iteration to reduce calculation time.

40

41

42

**5.2. Estimating the Candidate Hazard Standard Using the Response Surface**

After generating a response surface for range of candidate loadings, a rough estimate of the relationship between candidate loadings and blood lead levels will be known. Using this relationship, a set of candidate loadings can be estimated to correspond with a target blood lead level, and the model is run to determine if the target blood lead level is reached with sufficient precision. Because this analysis is composed of a large number of sampled distributions (Table 5-1), it is suspected that thousands of realizations will be required to reach a stable blood lead level distribution. Stability of the distribution will be assessed using statistical methods roughly comparing variability of the distribution to its median with variability measures generated by such techniques as the boot-strap method<sup>c</sup>.

**Table 5-1. Key Input Variables or Variable Groups Sampled in the Public and Commercial Buildings Model**

| Group  | Sampling independent or correlated? | Variable or Variable Group <sup>a</sup>              | Sampling Notes                |
|--|-------------------------------------|--|-------------------------------|
| Candidate hazard standards                           | Correlated                          | Dust lead loading, floor, commercial/public building | Fixed with each iteration     |
|  |                                     | Dust lead loading, sill, commercial/public building  | Fixed with each iteration     |
| Exposure location                                    | Independent                         | Time spent in each environment                       | Sampled, resampled annually   |
| Exposure   | Independent                         | Ingestion of lead in drinking water                  | Sampled, resampled annually   |
|  | Independent                         | Ingestion of lead in diet                            | Sampled, resampled annually   |
|  | Independent                         | Daily ingestion of dust and soil                     | Fixed, changes annually       |
|  | Independent                         | Ventilation rate                                     | Fixed, changes annually       |
|  | Independent                         | Lung absorption efficiency                           | Fixed                         |
| Lead loadings/ concentrations in environmental media | Correlated                          | Dust lead loading, floor, all other areas            | Sampled, once per realization |
|  |                                     | Dust lead loading, sill, all other areas             | Sampled, once per realization |
|  | Independent                         | Soil lead concentration, outdoors                    | Sampled, once per realization |
|  | Independent                         | Air lead concentration, indoors                      | Sampled, once per realization |
|  | Independent                         | Air lead concentration, outdoors                     | Sampled, once per realization |

<sup>a</sup> Variables mentioned above may represent multiple distributions, and therefore the number of sampled distributions will actually be greater than what is presented above. In addition, if additional or better input data are found, additional variables mentioned above may be sampled as well.

**5.3. Sensitivity Analysis**

To better understand each variable’s impact on the candidate hazard standards identified, a sensitivity analysis will be conducted on each variable. This sensitivity analysis will provide a better understanding of which variables are most influential to the model, and therefore which variables are most influential in determining the candidate hazard levels. This analysis will use

<sup>c</sup> The simulations will be run until the standard error of the 90<sup>th</sup> percentile value of the output blood lead distribution is estimated to be less than 10 per cent of its median.

1 methods consistent with considerations in the Agency intended to conform to current best  
2 practice.

3 All sensitivity analyses will be conducted in deterministic mode. Deterministic mode is defined  
4 using a single value for each variable (i.e., no sampling will occur). In deterministic mode, each  
5 unique group of input variables will have one unique output value. Because no sampling will  
6 occur, results will not be impacted by the convergence of output distributions.

7 Elasticity will be used to determine the impact of each input variable. Elasticity is defined as the  
8 percent change in a model output value (i.e., blood-lead level) that results from a fixed percent  
9 change in a model input variable value with all other variable values held to a constant baseline  
10 value. Baseline case is defined as the central tendency values for all variables in the model. By  
11 modifying each variable by the same percent change, elasticity can be compared across  
12 variables to better understand to which variables the model is most/least sensitive.

$$13 \quad \text{Elasticity} = \frac{\frac{y^1 - y^0}{y^0}}{\frac{x^1 - x^0}{x^0}}$$

14 where:

15  $y^1$  = blood lead level, sensitivity case

16  $y^0$  = blood lead level, baseline case

17  $x^1$  = property value, sensitivity case

18  $x^0$  = model input property value, baseline case

19 An elasticity of 1 means that a percent change in an input value is linearly related to a percent  
20 change in the output value. An elasticity of 0 means that changing the input value has no effect  
21 on the output value. A elasticity in absolute value less than 1 occurs when a percent change in an  
22 input value results in a greater percent change in an output value. An elasticity of  $| < 1 |$  occurs  
23 when a percent change in an input value results in a smaller percent change in an output value. A  
24 negative value for elasticity indicates that the output value varies in the opposite direction to the  
25 input value change.

26 For all characteristics (sampled or fixed), variability in a property can be nonlinear. To address  
27 this in the sensitivity analysis, two analyses will be conducted: a local analysis (representing  
28 small changes in a variable) and a global analysis (for larger changes). For the local analysis,  
29 each variable in the model will be varied by  $\pm 5\%$  from the central tendency; for the global  
30 analysis, each variable will be varied by  $\pm 50\%$  from the central tendency. If the elasticity of a  
31 variable is different between the local and global analysis, this indicates that this variable has a  
32 nonlinear relationship to blood lead.

33 Because the model will sample media concentrations from known distributions, additional  
34 information is known about the range of possible values from these distributions. Therefore, the  
35 sensitivity score will be calculated for variables which are sampled from a distribution. The  
36 sensitivity score is calculated by:

1 
$$\text{Sensitivity Score} = \text{Elasticity} * \frac{\sigma_x}{\mu_x}$$

2 Where:

3  $\sigma_x$  = standard deviation/geometric standard deviation of input distribution

4  $\mu_x$  = mean/geometric mean of input distribution

1 **6. Data Needs**

2 The quality of the results generated using the approach described in this document relies heavily  
3 on reliable input data. Among the most important data needs are:

- 4 • Media concentrations for residences;
- 5 • Media concentrations for public and commercial buildings;
- 6 • Media concentrations for near-roadway areas;
- 7 • Media concentrations for outdoors;
- 8 • Relationship between window sill and floor dust lead exposures;
- 9 • Inputs to the blood lead models; and
- 10 • Inputs to the mechanistic dust lead loading-to-concentration model.

11 This section discusses the data identified thus far for each of the types of data, with the exception  
12 of the inputs to the mechanistic loading-to-concentration model and those for the floor-dust-to-  
13 sill-dust correlation, which are discussed in Appendix A.

14 **6.1.1. Media concentrations for residences**

15 As shown in Table 3-1, the distribution of indoor dust floor loadings, indoor dust window sill  
16 loadings, and indoor air lead concentrations are needed in residences.

17 For the floor and window sill loadings, the HUD survey of lead-based paint in homes (USEPA  
18 1995) will be used. This survey provides data on wipe and vacuum samples of floor and window  
19 sill loadings in 312 homes. Distributions will be developed from these loadings to capture the  
20 distribution of lead loadings in the housing stock. The wipe sample loadings will be used in  
21 favor of the vacuum samples because they are expected to provide a better estimate of the total  
22 lead loading. The survey provides weighting factors used to update the data to the 1997 housing  
23 stock, and the weights will be incorporated when developing the distributions.

24 For the air distributions, the approach proposes to use the Air Quality System (AQS) monitoring  
25 system to develop suitable distributions (USEPA 2010b). In the system, each monitor is  
26 assigned a monitoring objective code, as shown in Table 6-1. In order to capture the typical  
27 exposure concentrations for the national population, data from all monitors with coverage in  
28 2009 and 2010 for the codes 6 (Population Exposure) and G (General/Background) will be  
29 pulled. The data will be annually-averaged, and a distribution across the available values will be  
30 developed. In order to capture the total lead content, the analysis will focus on lead Total  
31 Suspended Particulate (TSP) monitors.

32 These monitors provide outdoor air concentrations around the country. To generate the indoor  
33 concentrations, a factor will be applied to the outdoor concentrations to approximate the indoor  
34 concentration. Thatcher and Layton (1995) report that Colome et al. (1992) found an average  
35 indoor/outdoor ratio of 0.7 in 35 California homes. This is also the average indoor/outdoor ratio  
36 predicted by the approach’s mechanistic dust model when applied to the HUD data set (see  
37 Appendix A), suggesting the ratio is plausibly applied in this approach. Thus, the ambient  
38 concentration will be multiplied by 0.7 to convert to an approximate indoor concentration.

**Table 6-1. AQS Monitor Objective Codes**

| <b>Monitor Code</b> | <b>Monitor Objective</b>       |
|---------------------|--------------------------------|
| 0                   | UNKNOWN                        |
| 1                   | UPWIND BACKGROUND              |
| 2                   | MAX PRECURSOR EMISSIONS IMPACT |
| 3                   | MAX OZONE CONCENTRATION        |
| 4                   | EXTREME DOWNWIND               |
| 5                   | OTHER                          |
| 6                   | POPULATION EXPOSURE            |
| 7                   | SOURCE ORIENTED                |
| 8                   | REGIONAL TRANSPORT             |
| 9                   | WELFARE RELATED IMPACTS        |
| G                   | GENERAL/BACKGROUND             |
| H                   | HIGHEST CONCENTRATION          |
| I                   | INVALID CODE TEST              |

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**6.1.2. Media concentrations for public and commercial buildings**

As shown in Table 3-1, the distribution of indoor air lead concentrations are needed in public and commercial buildings to develop the lead hazard standards. The dust concentrations will be the target hazard standards and will not be approximated from literature data.

Data may not be available to separately define residential and public and commercial building ambient air concentrations. Thus, the approach will likely use the same ambient concentration as used in residences. An extensive literature search will be conducted to identify typical indoor/outdoor air concentration ratios in public and commercial buildings for use in converting to indoor concentrations.

**6.1.3. Media concentrations near roadways**

An exposure concentration in air is also required for the “traveling” microenvironment. Attempts will be made to locate air lead concentrations which are typical on and near roadways. Then, the assumption will be made that the “traveling” microenvironment concentration equals the outdoor ambient concentration.

**6.1.4. Media concentrations outdoors**

For the outdoor microenvironment, the approach requires outdoor soil concentrations. The HUD survey (USEPA 1995) provides soil concentrations at residences. These concentrations will be used to develop residential soil distributions.

For outdoor locations away from the home, available public and commercial soil lead concentrations will be compared to the residential values and a separate distribution will be developed if needed.

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**6.1.5. The relationship between window sill and floor exposures**

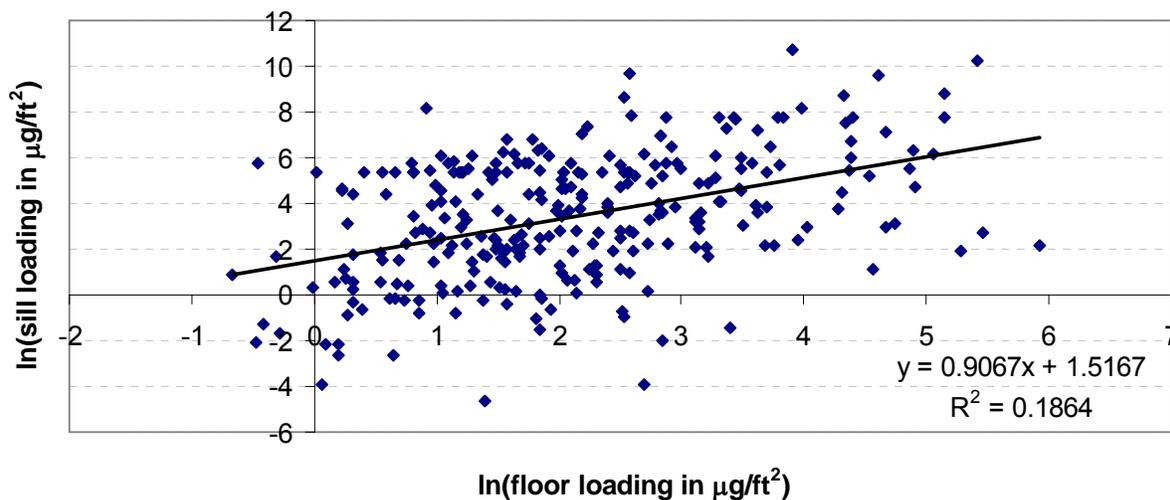
In order to combine the indoor dust concentrations into a single exposure level for model input, the floor and sill levels must be combined according to the approximate relative ingestion of each. The LRRP rule (USEPA 2008a) used a weighting strategy based on the surface area. This would give approximately 1% weighting to sills and 99% weighting to floors.

A literature search was conducted to determine if any other exposure assessments have made assumptions of the relative contributions of floor and sill. To date, only a single document has been found. The assessment focused on lead and arsenic exposures associated with the presence of indoor paint. It was submitted to the ATSDR and was prepared by the California Department of Health Services (CDC 2002). In the assessment, the assumption was made that sills contribute 1% in infants, 5% in toddlers, 17% in young children, 25% in older children, and 25% in adults. These values appear to represent the authors’ professional judgment and do not reflect any measurements that could inform the weighting strategy chosen for this approach. Consequently, the relative floor area assumption will be used.

In addition to combining the floor and sill concentrations into a single aggregate dust concentration, the candidate window sill hazard standard will need to be determined corresponding to each candidate floor hazard standard. Because these two loadings are expected to be correlated in a single building, the approach proposes to develop an empirical relationship to combine them in residences. One potential dataset is the HUD survey data (USEPA 1998). The data from homes constructed before 1980 were used to develop a preliminary relationship between floors and sills for this approach. Figure 6-1 shows the regression model for this dataset; details of this analysis are described in Appendix A. The data were natural-log-transformed, since doing so resulted in an apparently higher regression coefficient. The correlation between the variables indicates some correlation (r=0.43). The equation relating the two loadings would then be

$$Sill = 4.56 \times Floor^{0.91}$$

**Figure 6-1. Regression Relationship between Ln(Sill) and Ln(Floor) for the HUD Data**



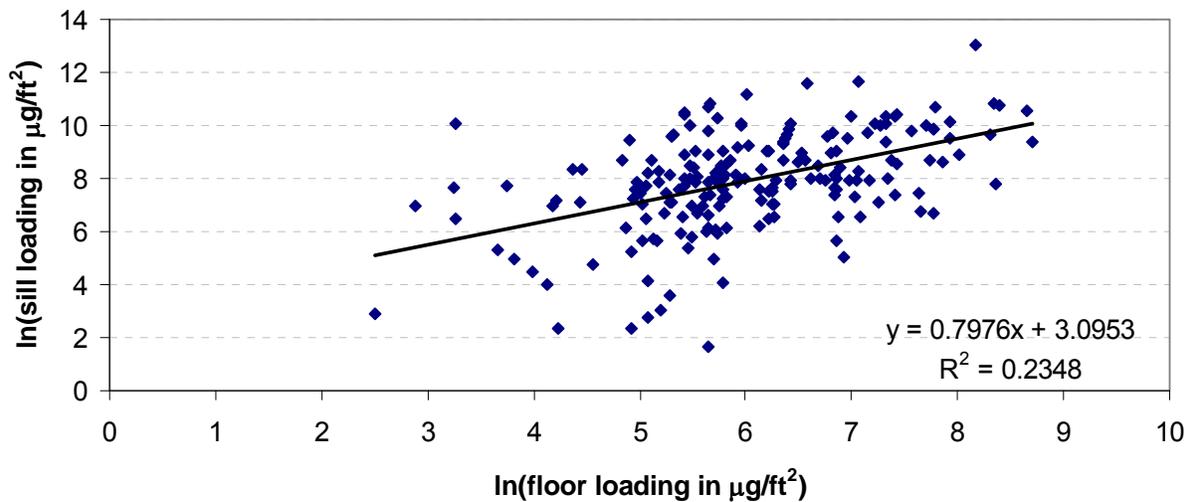
1 In addition, the Rochester data (Lanphear et al., 1998a) could be used to derive an empirical  
 2 relationship. As in the HUD data, the natural-log-transformed variables are better correlated  
 3 than the untransformed variables; the regression is presented in Figure 6-2. In this case, the  
 4 correlation appears slightly higher ( $r=0.48$ ) and the equation relating sill to floor loading would  
 5 be

$$Sill = 22.1 \times Floor^{0.80}$$

6  
 7 A literature search will be conducted to determine if additional details about the empirical  
 8 relationship can be found.

9  
 10 Both of these empirical relationships are more applicable to residences than to public and  
 11 commercial buildings. However, to date, no data have been found which could relate window  
 12 sill and floor loadings in public and commercial buildings. The approach proposes to use the  
 13 residential relationships, although this assumption will introduce uncertainty into the hazard  
 14 standard estimates.

15  
 16 **Figure 6-2. Regression Relationship between Ln(Sill) and Ln(Floor) for the Rochester**  
 17 **Data**



18

19 **6.1.6. Inputs to the blood lead models**

20 The blood lead models require a number of inputs in addition to the air, soil, and dust  
 21 concentrations. Table 6-2 shows the inputs and the proposed values for each of these inputs. As  
 22 a starting point, the selected values are the same as those used in the development of the benefits  
 23 analysis for the lead renovation and repair rule (USEPA 2008c). Several input values were then  
 24 updated with data from recently published literature. Other values, however, were found to still  
 25 reflect the best information available. These included the lead absorption fractions and the  
 26 fraction of ingested soil+dust which is soil.

27 In 2008, EPA published a new edition of its Child-Specific Exposure Factors Handbook, in  
 28 which updated values for total indoor/outdoor dust ingestion and ventilation rate were presented  
 29 (USEPA 2008b). Where ages were expressed as a range in that report, rates for intermediate

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1 ages were interpolated using linear trendlines. Mean and 95<sup>th</sup> percentile values are available for  
2 both the dust ingestion and the ventilation rates. For the dust ingestion, the mean and 95<sup>th</sup>  
3 percentile values will be used to establish a lognormal distribution which will then be sampled as  
4 part of the Monte Carlo simulation. For ventilation rates, the mean age-specific values will be  
5 used in developing the hazard standards. Because inhalation rates have been found in previous  
6 analyses not strongly to affect the predicted blood lead levels in children (USEPA 2006), this  
7 variable is not sampled in order to minimize the number of Monte Carlo realizations necessary to  
8 resolve the blood lead distribution.

9 For the dietary and water lead intakes, distributions will be generated using the LifeLine<sup>TM</sup>  
10 Model (The LifeLine Group 2008). This model will predict distributions of water and dietary  
11 lead intake for each medium by age group. Because the IEUBK includes both a water  
12 consumption term and a water concentration term, the consumption will be set to one liter per  
13 day and the intake will be used in place of the concentration.

14 The IEUBK value for maternal blood lead level has been updated using data from the most  
15 recent NHANES survey. These data from 2007 and 2008 (CDC 2009b) reveal that the nationally  
16 weighted GM blood lead level among women aged 18 through 45 has fallen over the last fifteen  
17 years to 0.847 µg/dL.

**Table 6-2. Proposed Blood Lead Model Input Values**

| Group                    | Variable  | Variable Name   | Variable Value                                       |                   |                   |                    |                    |                    |                    | Basis/Derivation   |
|--------------------------|---|---|--|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--|
|                          |   |   | IEUBK Default Age Ranges (Years)                     |                   |                   |                    |                    |                    |                    |  |
|                          |   |   | 0.5 to 1   | 1 to 2            | 2 to 3            | 3 to 4             | 4 to 5             | 5 to 6             | 6 to 7             |  |
| Inhalation               | Daily ventilation rate (cubic meters [m <sup>3</sup> ]/day) | Ventilation rate  | 5.4 (95%<br>8.1)                                     | 8.0 (95%<br>12.8) | 9.5 (95%<br>15.9) | 10.9 (95%<br>16.2) | 10.9 (95%<br>16.2) | 10.9 (95%<br>16.2) | 12.4 (95%<br>18.7) | EPA Child-Specific Exposure Factors Handbook (USEPA 2008b) with interpolation for intermediate ages  |
|                          | Absolute inhalation absorption fraction (unitless)          | <ul style="list-style-type: none"> <li>Lung absorption (IEUBK)</li> <li>Absolute respiratory absorption fraction (Leggett)</li> </ul> | 0.42   |                   |                   |                    |                    |                    |                    | USEPA (1989) Appendix A  |
|                          | Indoor air Pb concentration                                 | Indoor air Pb concentration (percentage of outdoor)   | 100%   |                   |                   |                    |                    |                    |                    | These values are taken directly into account when developing the exposure concentrations   |
|                          | Time spent outdoors   | Time spend outdoors (hours/day)   | Not used   |                   |                   |                    |                    |                    |                    |  |
| Drinking Water Ingestion | Water consumption (L/day)                                   | Water consumption (L/day)   | 1  | 1                 | 1                 | 1                  | 1                  | 1                  | 1                  | These values are set to 1, since the water consumption will be incorporated into the water ingestion estimate used in the next row.  |
|                          | Water Pb concentration (µg/L)                               | Pb concentration in drinking water (µg/L)   | Distribution to be estimated from the LifeLine model |                   |                   |                    |                    |                    |                    | The LifeLine™ model will be used to estimate the distribution of lead intake from water. Because the water consumption is set to 1 in the model, the intakes can be entered in place of the lead concentrations. |
|                          | Absolute absorption   | <ul style="list-style-type: none"> <li>Total percent accessible (IEUBK)</li> <li>Absolute GI</li> </ul>                               | 50 %<br>(Single value used across all age ranges)    |                   |                   |                    |                    |                    |                    | Assumed similar to dietary absorption (see "Total percent  |

**Table 6-2. Proposed Blood Lead Model Input Values**

| Group                                       | Variable  | Variable Name  | Variable Value                                       |  |  |  |  |  |  | Basis/Derivation   |
|---|---|--|--|--|--|--|--|--|--|--|
|   |   |  | IEUBK Default Age Ranges (Years)                     |  |  |  |  |  |  |  |
|   |   |  | 0.5 to 1   | 1 to 2   | 2 to 3   | 3 to 4   | 4 to 5   | 5 to 6   | 6 to 7   |  |
|   | (unitless)  | absorption fraction (Leggett)  |  |  |  |  |  |  |  | accessible" under Diet below).   |
| Diet  | Dietary Pb intake (µg/day)                                    | Dietary Pb intake (µg/day)   | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | Distribution to be estimated from the LifeLine model | The LifeLine™ model will be used to estimate the distribution of dietary intake by age group   |
|   | Absolute absorption (unitless)                                | (1)Total percent accessible (IEUBK)<br>(2) Absolute GI absorption fraction   | 50%  |  |  |  |  |  |  | Alexander et al. (1974) and Ziegler et al. (1978) as cited in USEPA (2006, section 4.2.1)  |
| Outdoor Soil/Dust and Indoor Dust Ingestion | Outdoor soil/dust and indoor dust weighting factor (unitless) | <ul style="list-style-type: none"> <li>Outdoor soil/dust and indoor dust ingestion weighting factor (percent outdoor soil/dust) (IEUBK)</li> <li>Outdoor soil/dust and indoor dust ingestion rates calculated separately using same proportion of outdoor soil/dust ingestion (Leggett)</li> </ul> | 45 percent   |  |  |  |  |  |  | This is the percent of total ingestion that is outdoor soil/dust. Value reflects best judgment and consideration (results published by van Wijnen et al. (1990), as cited in (USEPA, 1989). The van Wijnen et al. study examined at tracer studies of ingestion rates for rainy days and non-rainy days. It was assumed that rainy days were associated with all outdoor soil/dust ingestion and non-rainy days were associated with a combination of outdoor soil/dust and indoor dust with the delta representing outdoor soil/dust. |

**Table 6-2. Proposed Blood Lead Model Input Values**

| Group | Variable  | Variable Name   | Variable Value                                  |   |   |   |   |   |   | Basis/Derivation   |
|-------|---|---|---|---|---|---|---|---|---|--|
|       |   |   | IEUBK Default Age Ranges (Years)                |   |   |   |   |   |   |  |
|       |   |   | 0.5 to 1  | 1 to 2                                  | 2 to 3                                  | 3 to 4                                  | 4 to 5                                  | 5 to 6                                  | 6 to 7                                  |  |
|       | Total indoor dust + outdoor soil/dust ingestion (mg/day)                            | Amount of outdoor soil/dust and indoor dust ingested daily (mg)   | Distribution estimated from percentiles         | Distribution estimated from percentiles | Distribution estimated from percentiles | Distribution estimated from percentiles | Distribution estimated from percentiles | Distribution estimated from percentiles | Distribution estimated from percentiles | Distribution estimated from the EPA Child-Specific Exposure Factors Handbook (USEPA 2008b), excluding cases of soil-pica and geophagy  |
|       | Absolute gastrointestinal absorption (outdoor soil/dust and indoor dust) (unitless) | <ul style="list-style-type: none"> <li>• Total percent accessible (IEUBK)</li> <li>• Absolute GI absorption fraction (Leggett)</li> </ul> | 0.30 for both outdoor soil/dust and indoor dust |   |   |   |   |   |   | (USEPA, 1989) reflects evidence that Pb in indoor dust and outdoor soil/dust is as accessible as dietary Pb and that indoor dust and outdoor soil/dust ingestion may occur away from mealtimes (resulting in enhanced absorption relative to exposure during meal events). |
| Other | Maternal PbB (µg/dL)  | Maternal PbB concentration at childbirth, µg/dL   | 0.847   |   |   |   |   |   |   | NHANES 2007-2008, national weighted GM of all women aged 18-45 (CDC 2009b)   |



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## **Appendix A. Loading to Concentration Conversion Methods**



The indoor lead hazard standard prescribes the amount of lead allowed on the surface per unit area (lead loading). The blood lead models, however, cannot accept lead loadings as inputs. Instead, they require the lead concentration, or the amount of lead per mass of dust. Thus, as part of the derivation of the hazard standard, dust loadings must be converted to dust concentrations for input into the blood lead models. Two different estimates have been developed for this approach, based on two different methodologies: 1) a statistical regression model and 2) a mechanistic model. Sections A.1 through A.3 describe these estimates and highlight the strengths and limitations of each. Section A.4 describes the development of the regression used for the relationship between floor lead dust loading and window sill lead dust loading.

### A.1 Development of a Regression Equation

The National Survey of Lead-Based Paint in Housing ("HUD Survey Data") was used to develop a loading-to-concentration regression equation for this approach. The data, available in Appendix C-1 in a risk assessment (USEPA, 1998), provide information on wipe sample lead dust loadings, vacuum sample lead dust loadings, and blue nozzle lead concentrations on the floor for over 312 homes in different vintage categories: Pre1940, 1940-1959, 1960-1979, and Post1980. It is anticipated that the wipe samples better capture the total lead present in the home; the vacuum samples are subject to vacuum collection efficiencies. Thus, the wipe loadings were paired with the blue nozzle concentrations at each home to develop the loading-to-concentration statistical relationship. By doing so, the assumption is made that the concentration is roughly uniform across all particles and the particles collected by the blue nozzle device are representative of the true average concentration. In order to focus on the homes containing lead paint, only the data from the older three vintage categories were included. This eliminated 28 data points from the dataset. Some statistics from the reduced dataset are provided in Table A-1. In general, the spread in the data is large and covers loadings up to 375  $\mu\text{g}/\text{ft}^2$  and concentrations up to 50,400  $\mu\text{g}/\text{g}$ . The range of considered hazard standards is below the 95<sup>th</sup> percentile loadings, so the results of the regression are anticipated to apply to the hazard standard in residences.

**Table A-1. Statistics from the HUD Survey Data**

|                             | Loading<br>( $\mu\text{g}/\text{ft}^2$ ) | Concentration<br>( $\mu\text{g}/\text{g}$ ) |
|-----------------------------|--|---|
| Average                     | 20.99                                    | 559.08                                      |
| Min                         | 0.51                                     | 0.09  |
| Max                         | 375.00                                   | 50400.00                                    |
| 5 <sup>th</sup> percentile  | 1.25                                     | 33.85                                       |
| 25 <sup>th</sup> percentile | 3.27                                     | 101.75                                      |
| 50 <sup>th</sup> percentile | 7.43                                     | 201.00                                      |
| 75 <sup>th</sup> percentile | 17.38                                    | 374.25                                      |
| 95 <sup>th</sup> percentile | 96.10                                    | 1522.50                                     |

From the raw data, each loading and concentration was transformed by taking the natural log. Then, the regression was carried out using the untransformed variables and also the natural-log-transformed variables. Table A-2 shows the results of each regression.

**Table A-2. Regression Analysis Results**

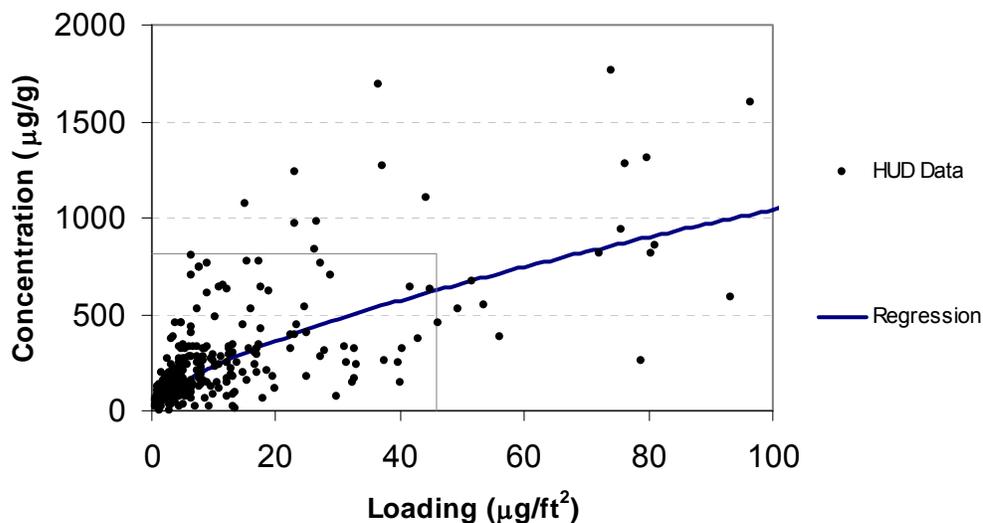
| Data                    | Variable  | Coefficient | Standard Error of Coefficient | t-stat | p-value | F-stat, p-level | Adjusted R2 |
|-------------------------|-----------|-------------|-------------------------------|--------|---------|-----------------|-------------|
| Untransformed           | Intercept | 159.74      | 195.86                        | 0.82   | 0.42    | 19.88, <0.0000  | 0.065       |
|                         | Slope     | 19.02       | 4.26                          | 4.46   | <0.0000 |                 |             |
| Natural-log-transformed | Intercept | 3.93        | 0.10                          | 38.11  | <0.0000 | 246.75, <0.0000 | 0.465       |
|                         | Slope     | 0.6655      | 0.42                          | 15.71  | <0.0000 |                 |             |

The data are positively skewed, and the regression analysis reveals that the log-transformed data provide a regression with a larger adjusted R<sup>2</sup> value. Thus, the log-transformed relationship is chosen, and after accounting for the natural log transformation, the equation relating concentration and loading is:

$$Concen = 50.96 \times Loading^{0.6553}$$

Figure A-1 below shows the raw data and the regression relationship. The gray lines represent the 90<sup>th</sup> percentile in the loading and the concentration.

**Figure A-1. HUD Data and the Regression Relationship**



## A.2 Development of a Mechanistic Dust Model

The mechanistic model is designed to capture the physical transfer of mass from one medium to another under the assumption of mass balance. Previous studies have also built mass balance models of indoor dust. Allott et al. (1994) constructed a mass balance model to estimate the

residence time of contaminated soil particles in the indoor environment based on observations in four homes in England contaminated by the Chernobyl incident. Thatcher and Layton (1995) constructed an indoor mass balance model of a home in California to estimate deposition rates, resuspension rates, and infiltration factors. Recognizing the key role of tracked-in soil on indoor dust loadings, Johnson (2008) built the DIRT model simulating the spatial pattern of tracked-in soil for a given total soil mass flux into the home. Layton and Beamer (2009) built a model simulating tracked-in soil and penetration of outdoor air and the subsequent physical processes governing indoor dust loadings. These models cannot be readily applied for developing an approach for the lead hazard standards, however, because they do not include any dust source from lead-containing paint. A new model was constructed for the hazard standard approach and the coefficients were optimized against all available data, as described below. Where applicable, the resulting coefficients are compared to those found in the above studies to help frame the model in the existing literature. This mechanistic model is deterministic in its underlying nature.

The general form of the mass balance equation for a single compartment of interest is:

$$\frac{d[Mass]}{dt} = Flux\ of\ Mass\ In - Flux\ of\ Mass\ Out$$

where:

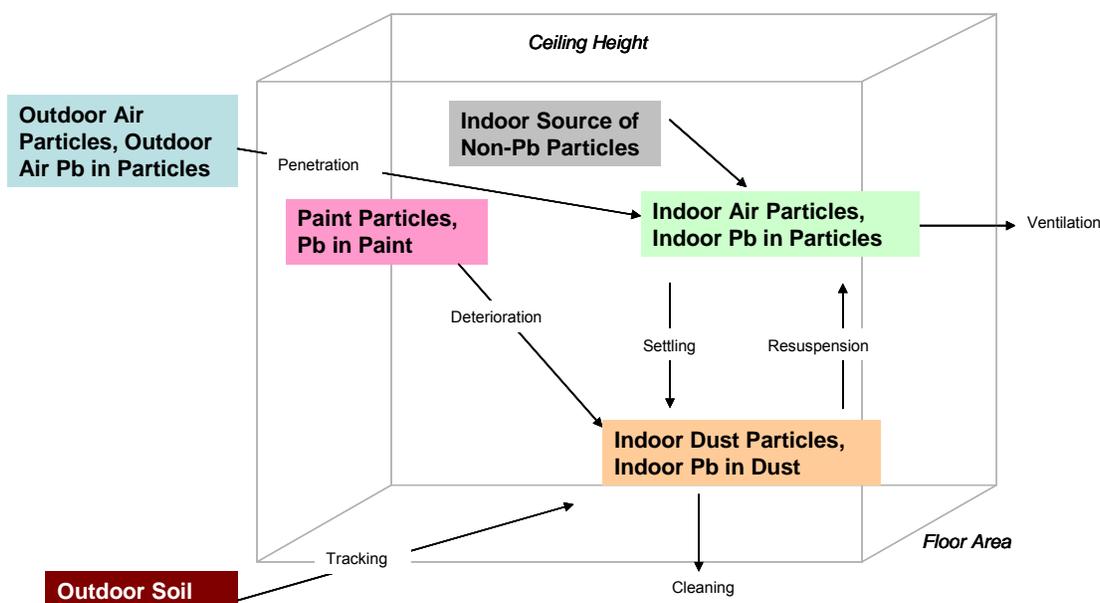
- $d[Mass]/dt$  = change over time of the mass
- $Flux\ of\ Mass\ In$  = flux of mass into the compartment
- $Flux\ of\ Mass\ Out$  = flux of mass out of the compartment

In the dust model, two “compartments” of interest are defined: the indoor air and the floor. Both of these compartments will contain particulates associated with indoor dust, and by parameterizing the processes that govern the flux of mass to and from each compartment, the model can provide an inventory of dust in the air and on the floor through time.

In the above equation, “mass” could refer to either the mass of lead that penetrates the home and settles on the floor in the dust or it could refer to the mass of the dust particles themselves. Because the blood lead model needs inputs of lead dust concentration, the mechanistic model must separately account for both the mass of lead and the mass of dust particulate that accumulates on the floor. Then, by dividing the total lead mass by the total dust mass, the model provides an estimate of the average lead dust concentration. Thus, for each compartment there are two separate equations, one for the lead mass and one for the dust particulate mass.

The dominant sources of lead to the indoor dust are ambient air particles which penetrate the indoor environment and settle on the floor, outdoor soil particles which are tracked into the home, and lead-containing paint which flakes or chips off the walls and settles to the floor. Dust particles have the same sources, although non-lead dust particles are also formed indoors through human activities such as cooking and smoking and by the accumulation of human and pet dander. Figure A-2 shows a schematic of the various lead and particulate mass flux terms used in the mechanistic model to account for all sources and sinks of mass.

Figure A-2. Mechanistic Indoor Dust Model Schematic



For the indoor air compartment, the fluxes for mass include penetration of air and particles from outdoors, ventilation of indoor air back to the outdoor environment, deposition of mass out of the air, resuspension of accumulated mass on the floor back into the air, generation due to indoor sources (where cooking and smoking are thought to dominate these sources), and generation due to the formation of human and pet dander<sup>d</sup>:

$$\frac{dINAIR_{Pb}}{dt} = Penetration\ Flux_{Pb} - Ventilation\ Flux_{Pb} - Deposition\ Flux_{Pb} + Resuspension\ Flux_{Pb} + Indoor\ Sources_{Pb} + Dander\ Sources_{Pb}$$

$$\frac{dINAIR_{part}}{dt} = Penetration\ Flux_{part} - Ventilation\ Flux_{part} - Deposition\ Flux_{part} + Resuspension\ Flux_{part} + Indoor\ Sources_{part} + Dander\ Sources_{part}$$

where:

---

<sup>d</sup> The presence of an HVAC system will tend to re-circulate indoor air, passing the air through a filter with each circulation. This system will tend to remove mass from the indoor environment (both in the air and on the floor) and act as a further sink. Because the circulation rate and filtration efficiency of such systems has not been comprehensively described in the literature and because use of such systems changes across the seasons and different geographic regions, removal of mass during recirculation is not included in the mechanistic model.

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- $dINAIR_{pb}/dt$  = change in time of the indoor air lead mass  
 $dINAIR_{part}/dt$  = change in time of the indoor air particulate mass  
*Penetration Flux* = penetration of air containing particles from outdoors  
*Ventilation Flux* = ventilation of indoor air back to the outdoor environment  
*Deposition Flux* = deposition of mass out of the air  
*Resuspension Flux* = resuspension of accumulated mass on the floor back into the air  
*Indoor Sources* = generation of mass due to indoor sources such as cooking or smoking  
*Dander Sources* = generation of mass due to human and pet dander

In general, each flux is parameterized as either a constant source or as the mass of the "donor" compartment multiplied by the rate (expressed in reciprocal time) of the physical exchange process. In some cases, an efficiency factor is also included to account for any filtration of lead associated with the process. In addition, there is a separate flux term for the lead mass and for the particulate equations. For the *Penetration Flux*,

$$Penetration\ Flux_{pb} = AER \times P \times PbAIR \times V$$

$$Penetration\ Flux_{part} = AER \times P \times PartAIR \times V$$

where:

- Penetration Flux<sub>pb</sub>* = penetration of air lead from outdoors (µg/h)  
*Penetration Flux<sub>part</sub>* = penetration of air particles from outdoors (g/h)  
*AER* = air exchange rate (h<sup>-1</sup>)  
*P* = penetration efficiency (unitless)  
*PbAIR* = concentration of lead in ambient air (µg/m<sup>3</sup>)  
*PartAIR* = concentration of particles in ambient air (g/m<sup>3</sup>)  
*V* = volume of the house (m<sup>3</sup>)

Because the air exchange rate (*AER*) specifies the number of times the indoor air is replaced by outdoor air in a given hour, it represents both the rate of penetration in and ventilation out. The ventilation flux out of the house is thus given by:

$$Ventilation\ Flux_{pb} = AER \times INAIR_{pb}$$

$$Ventilation\ Flux_{part} = AER \times INAIR_{part}$$

where:

- Ventilation Flux<sub>pb</sub>* = ventilation of indoor lead in air back to the outdoor environment (µg/h)  
*Ventilation Flux<sub>part</sub>* = ventilation of indoor particulate in air back to the outdoor environment (g/h)

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$AER$  = air exchange rate ( $h^{-1}$ )

$INAIR_{pb}$  = indoor mass of lead in air ( $\mu g$ )

$INAIR_{part}$  = indoor mass of particulate in air (g)

The deposition flux (*Deposition Flux*) is defined as the amount of mass in the air times a deposition rate:

$$Deposition\ Flux_{pb} = D \times INAIR_{pb}$$

$$Deposition\ Flux_{part} = D \times INAIR_{part}$$

where:

$Deposition\ Flux_{pb}$  = deposition of lead out of the air ( $\mu g/h$ )

$Deposition\ Flux_{part}$  = deposition of particulate out of the air (g/h)

$D$  = deposition rate ( $h^{-1}$ )

$INAIR_{pb}$  = indoor mass of lead in air ( $\mu g$ )

$INAIR_{part}$  = indoor mass of particulate in air (g)

For resuspension, the amount of resuspended material depends on the total available mass on the floor multiplied by a resuspension rate:

$$Resuspension\ Flux_{pb} = R \times FLOOR_{pb}$$

$$Resuspension\ Flux_{part} = R \times FLOOR_{part}$$

where:

$Resuspension\ Flux_{pb}$  = resuspension of lead out of the air ( $\mu g/h$ )

$Resuspension\ Flux_{part}$  = deposition of particulate out of the air (g/h)

$R$  = deposition rate ( $h^{-1}$ )

$FLOOR_{pb}$  = mass of lead on the floor ( $\mu g$ )

$FLOOR_{part}$  = mass of particulate on the floor (g)

For the indoor sources of mass, each source is set equal to a constant rate:

$$IndoorSources_{pb} = 0$$

$$DanderSources_{pb} = 0$$

$$IndoorSources_{part} = CookingRate_{part} + SmokingRate_{part}$$

$$DanderSources_{part} = DanderRate_{part}$$

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where:

- $IndoorSources_{Pb}$  = source of lead due to cooking and smoking ( $\mu\text{g/h}$ );  
assumed to be zero.
- $DanderSources_{Pb}$  = source of lead due to formation of dander ( $\mu\text{g/h}$ ); assumed  
to be zero.
- $IndoorSources_{Part}$  = source of particulate due to cooking and smoking (g/h)
- $CookingRate_{Part}$  = rate of generation of particulate mass due to cooking  
(g/h)
- $SmokingRate_{Part}$  = rate of generation of particulate mass due to smoking  
(g/h)
- $DanderSources_{Part}$  = source of particulate due to formation of dander (g/h)
- $DanderRate_{Part}$  = rate of generation of particulate mass due to dander  
(g/h).

So, using the penetration, ventilation, deposition fluxes, and indoor source terms, the equation for the change in time of the indoor air lead mass is:

$$\frac{dINAIR_{Pb}}{dt} = AER \times P \times PbAIR \times V - AER \times INAIR_{Pb} - D \times INAIR_{Pb} + R \times FLOOR_{Pb}$$

$$\frac{dINAIR_{Part}}{dt} = AER \times P \times PartAIR \times V - AER \times INAIR_{Part} - D \times INAIR_{Part} + R \times FLOOR_{Part} +$$

$$CookingRate_{Part} + SmokingRate_{Part} + DanderRate_{Part}$$

where:

- $dINAIR_{Pb}/dt$  = change in time of the indoor air lead mass ( $\mu\text{g/h}$ )
- $dINAIR_{Part}/dt$  = change in time of the indoor air particulate mass (g/h)
- $INAI_{Pb}$  = indoor mass of lead in air ( $\mu\text{g}$ )
- $INAI_{Part}$  = indoor mass of particulate in air ( $\mu\text{g}$ )
- $FLOOR_{Pb}$  = mass of lead on the floor ( $\mu\text{g}$ )
- $FLOOR_{Part}$  = mass of particulate on the floor (g)
- $PbAIR$  = concentration of lead in ambient air ( $\mu\text{g/m}^3$ )
- $PartAIR$  = concentration of particulate in ambient air ( $\text{g/m}^3$ )
- $AER$  = air exchange rate ( $\text{hour}^{-1}$ )
- $P$  = penetration efficiency (unitless)
- $V$  = volume of the house ( $\text{m}^3$ )
- $D$  = deposition rate ( $\text{h}^{-1}$ )
- $R$  = resuspension rate ( $\text{h}^{-1}$ )

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$CookingRate_{part}$  = rate of generation of particulate mass due to cooking  
(g/h)

$SmokingRate_{part}$  = rate of generation of particulate mass due to smoking  
(g/h)

$DanderRate_{part}$  = rate of generation of particulate mass due to dander  
(g/h).

For the indoor floor dust compartment (*FLOOR*), the fluxes include deposition of lead from the air onto the floor, resuspension of lead from the floor into the air, flaking of paint from the walls, tracking of lead from outdoor soil, and removal of lead due to routine cleaning:

$$\frac{dFLOOR_{pb}}{dt} = Deposition Flux_{pb} - Resuspension Flux_{pb} + PaintFlux_{pb} + TrackingFlux_{pb} - Cleaning Flux_{pb} \quad (\text{Equation 1A})$$

$$\frac{dFLOOR_{part}}{dt} = Deposition Flux_{part} - Resuspension Flux_{part} + PaintFlux_{part} + TrackingFlux_{part} - Cleaning Flux_{part} \quad (\text{Equation 1B})$$

where:

- $dFLOOR/dt$  = change in time of the indoor floor mass
- $Deposition Flux$  = deposition of mass out of the air onto the floor
- $Resuspension Flux$  = resuspension of mass from the floor into the air
- $Paint Flux$  = flaking of lead-containing paint onto the floor
- $Tracking Flux$  = tracking of soil inside from outdoors
- $Cleaning Flux$  = removal of lead due to routine cleaning.

The deposition flux (*Deposition Flux*) and resuspension flux (*ResuspensionFlux*) retain the same form as in the *INAIR* equations. The paint flux is parameterized using a paint chipping fraction, a wall area expressed as the wall loading multiplied by the house volume, and lead paint concentration for the lead mass and the same paint chipping fraction and wall area with a coverage density for the particulate mass. The chipping fraction is explicitly assumed to account for the mass that falls on the floor rather than any mass that lands on window sills or other surfaces:

$$Paint Flux_{pb} = PbPaintConcen \times ChipFraction \times V \times WallLoading \times UnitConv$$

$$Paint Flux_{part} = CoverageDens \times ChipFraction \times V \times WallLoading \times UnitConv$$

where:

- $PaintFlux_{pb}$  = generation of lead in air due to deterioration of lead-containing paint (µg/h)
- $PaintFlux_{part}$  = generation of particulate in air due to deterioration of lead-containing paint (µg/h)

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- PbPaintConcen* = lead concentration in the paint (mg/cm<sup>2</sup>)  
*ChipFraction* = fraction of total wall area which flakes from the walls per year (year<sup>-1</sup>)  
*V* = volume of the home (m<sup>3</sup>)  
*WallLoading* = area of wall space per unit volume of the home (m<sup>2</sup>/m<sup>3</sup>)  
*CoverageDens* = the coverage density of paint on the wall (g/m<sup>2</sup>)  
*UnitConv* = unit conversion necessary to make units consistent (1 year/8760 h).

The tracking flux (*TrackingFlux*) is parameterized specifically according to the limited data available about the process. Von Lindern et al. (2003) measured the amount of particulate deposited on front mats in 276 houses in two locations near the Bunker Hill Superfund Site. The lead levels reported in the paper are expected to be high-end and are not expected to represent general population exposures. This approach assumes, however, that the rate of accumulation of dust (as opposed to the lead in the dust) on doormats is not strongly affected by the location and can be used to represent a national population of homes. In addition, Thatcher and Layton (1995) measured the difference between particulate accumulation in tracked and untracked areas in the home as well as the amount on the front mat. From these two data sources, it is possible to estimate a distribution of mat particulate accumulation rates as well as the fraction of material that remains on the mat compared to being tracked into the home. For this reason, the tracking is parameterized as:

$$Tracking\ Flux_{pb} = PbSoilConcen \times TrackingRate \times \frac{(1 - MatFrac)}{MatFrac}$$

$$Tracking\ Flux_{part} = TrackingRate \times \frac{(1 - MatFrac)}{MatFrac}$$

where:

- TrackingFlux<sub>pb</sub>* = accumulation of tracked-in lead on the floor (µg/h)  
*TrackingFlux<sub>part</sub>* = accumulation of tracked-in particulate on the floor (g/h)  
*PbSoilConcen* = concentration of lead in the tracked-in soil (µg/g)  
*TrackingRate* = rate at which particulate is deposited on front mats (g/h)  
*MatFrac* = fraction of total tracked material which is deposited on the front mat (as opposed to the remainder of the house) (unitless).

The cleaning flux (*Cleaning Flux*) is parameterized assuming a cleaning efficiency (*CE*) and cleaning frequency (*CF*) and multiplying these by the mass on the floor (*FLOOR*):

$$Cleaning\ Flux_{pb} = CE \times CF \times FLOOR_{pb}$$

$$Cleaning\ Flux_{part} = CE \times CF \times FLOOR_{part}$$

where:

- Cleaning Flux<sub>pb</sub>* = removal of lead due to routine cleaning (µg/h)

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- Cleaning Flux<sub>part</sub>* = removal of particulate due to routine cleaning (g/h)  
*CE* = cleaning efficiency (unitless)  
*CF* = cleaning frequency (cleanings/h)  
*FLOOR<sub>Pb</sub>* = mass of lead on the floor (µg)  
*FLOOR<sub>part</sub>* = mass of particulate on the floor (g).

In the above parameterization, the lead and particulate appear to be cleaned separately, although they are actually present on the same physical particles; by applying the same cleaning equation to both the mass of lead and the mass of particulate, the assumption is made that cleaning occurs over the whole floor and the concentration of lead on the particles is roughly uniform across all particles on the floor.

Combining the floor fluxes then gives:

$$\begin{aligned} \frac{dFLOOR_{Pb}}{dt} = & D \times INAIR_{Pb} - R \times FLOOR_{Pb} + \\ & PbPaintConcen \times ChipFraction \times V \times WallLoading \times UnitConv + \\ & PbSoilConcen \times TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} - CE \times CF \times FLOOR_{Pb} \end{aligned} \quad \text{(Equation 2A)}$$

$$\begin{aligned} \frac{dFLOOR_{part}}{dt} = & D \times INAIR_{part} - R \times FLOOR_{part} + \\ & PbCoverageDens \times ChipFraction \times V \times WallLoading \times UnitConv + \\ & TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} - CE \times CF \times FLOOR_{part} \end{aligned} \quad \text{(Equation 2B)}$$

where:

- dFLOOR<sub>Pb</sub>/dt* = change in time of the indoor floor lead mass (µg/h)  
*dFLOOR<sub>part</sub>/dt* = change in time of the indoor floor particulate mass (g/h)  
*INAIPR<sub>Pb</sub>* = indoor mass of lead in air (µg)  
*INAIPR<sub>part</sub>* = indoor mass of particulate in air (µg)  
*FLOOR<sub>Pb</sub>* = mass of lead on the floor (µg)  
*FLOOR<sub>part</sub>* = mass of particulate on the floor (g)  
*D* = deposition rate (h<sup>-1</sup>)  
*R* = resuspension rate (h<sup>-1</sup>)  
*PbPaintConcen* = lead concentration in the paint (mg/cm<sup>2</sup>)  
*ChipFraction* = fraction of total wall area which flakes from the walls per year (year<sup>-1</sup>)  
*V* = volume of the home (m<sup>3</sup>)

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- WallLoading* = area of wall space per unit volume of the home (m<sup>2</sup>/m<sup>3</sup>)  
*CoverageDens* = the coverage density of paint on the wall (g/m<sup>2</sup>)  
*UnitConv* = unit conversion necessary to make units consistent 1  
 year/8760 h)  
*PbSoilConcen* = concentration of lead in the tracked-in soil (μg/g)  
*TrackingRate* = rate at which particulate is deposited on front mats (g/h)  
*MatFrac* = fraction of total tracked material which is deposited on  
 the front mat (as opposed to the remainder of the  
 house) (unitless)  
*CE* = cleaning efficiency (unitless)  
*CF* = cleaning frequency (cleanings/h).

The above equations can be converted to difference equations by assuming a discrete time step and the model can be integrated forward in time to describe the lead and particulate accumulation at any moment. The derivation of the hazard standard, however, assumes that conditions in the home are relatively static, so the steady-state solution to the above equations can capture the long-term air and floor lead and particulate masses. To obtain the steady-state solution for each compartment, the derivative terms are set to zero, so that nothing is changing in time. Using equations (1A) and (2A) to solve for the floor lead mass at steady state gives:

$$FLOOR_{pb} = \frac{1}{(R + CE \times CF)(AER + D) - RD} \times$$

$$[PbPaintConcen \times ChipFraction \times V \times WallLoading \times UnitConv \times (AER + D) +$$

$$PbSoilConcen \times TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} \times (AER + D) +$$

$$PbAir \times D \times AER \times P \times V]$$

This equation is linear with respect to the lead paint, soil, and outdoor air concentrations and gives the expected floor lead accumulation in the house at steady state. Similarly, using equations (1B) and (2B) to solve for the floor particulate mass at steady state gives:

$$FLOOR_{part} = \frac{1}{(R + CE \times CF)(AER + D) - RD} \times$$

$$[CoverageDens \times ChipFraction \times V \times WallLoading \times UnitConv \times (AER + D) +$$

$$TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} \times (AER + D) +$$

$$PartAir \times D \times AER \times P \times V +$$

$$D \times (CookingRate + SmokingRate + DanderRate)]$$

In order to find the relationship between the floor loading and the concentration, we define the equation:

$$Loading = Slope \times Concen$$

By using the floor lead mass, the floor particulate mass, and the area of the house, the *slope* in the above equation is given by

$$slope = \frac{1}{[(R + CE \times CF)(AER + D) - RD] \times V \times FloorLoading} \times [CoverageDens \times ChipFraction \times V \times WallLoading \times UnitConv \times (AER + D) + TrackingRate \times \frac{(1 - MatFrac)}{MatFrac} \times (AER + D) + PartAir \times D \times AER \times P \times V + D \times (CookingRate + SmokingRate + DanderRate)] \quad (\text{Equation 3})$$

This final equation is the conversion used in the approach to convert loadings to concentrations (and vice versa).

### A.2.1 Input Values for the Mechanistic Model

Values were selected from the literature for input into the model equations. Table A-3 lists all the input values in the *slope* variable. The lead paint concentration, lead air concentration, and lead soil concentration are also needed for the calculation of loadings and concentrations, and these are adjusted according to the dataset being modeled. Each variable includes a central tendency estimate intended to be nationally representative. For variables where distribution information is available and implemented in the model, the geometric mean and geometric standard deviation from the estimated lognormal distribution are also shown.

The house volume (*V*) was taken from the 2001 Residential Energy Consumption Survey (RECS) (US DOE, 2001). Binned data were used to estimate the lognormal distribution, and the central tendency estimate is the mean of the calculated distribution. The wall loading (*WallLoading*) and floor loading (*FloorLoading*) were taken from the Exposure Factors Handbook (USEPA, 1997a).

The air exchange rate (*AER*) was taken from the Exposure Factors Handbook (USEPA, 1997a) recommendation. Other information by time of year and region of the country is available, but these data have not been added to the model. The penetration efficiency (*P*) has been modeled for particles of various size classes and has been measured in a few field studies to be less than one (e.g., Dockery and Spengler, 1981; Freed et al., 1983; Liu and Nazaroff, 2001). Unlike the above studies, however, in a field study that simultaneously controlled for penetration and deposition, the penetration efficiency was found to be near 1 for all size classes (Thatcher and Layton, 1995); similar results were also reported for PM<sub>2.5</sub> for homes in California (Ozkaynak et al., 1996) and for a model of NHEXAS Midwest homes (P=0.96; Layton and Beamer, 2009). Thus, the penetration efficiency was set to 1 for the mechanistic model.

The deposition rate (*D*) was set to 0.65 h<sup>-1</sup> based on information in the Exposure Factors Handbook (US EPA, 1997a) based on a paper by Wallace (1996). The value for PM<sub>10</sub> was selected, as most of the suspended particulate in the home is expected to fall within this size range.

The resuspension rate (*R*) varies strongly according to what activity is being undertaken in the home. Resuspension rates during periods where humans are still or absent are lower than during periods of human activity. Vacuuming, in particular, introduces much higher resuspension. For

the approach model, an intermediate value was taken from values calculated in Layton and Beamer (2009) for homes in the NHEXAS Midwest region ( $1.4 \times 10^{-4} \text{ h}^{-1}$ ). This value incorporates the increased resuspension rate during an episode when one person was walking through the room.

An extensive literature review was conducted, but no information could be found for typical paint chipping rates in homes. A few approaches were implemented in the model, including a constant rate, a rate that was exponential in time, and a rate that depended on the overall wall area. Based on a review of the results of the calibration exercise and further review of the physical processes, the latter approach was selected. The chipping fraction was then found by calibrating the mean model predictions against the HUD dataset, as discussed in section A.2.2. The value found to best fit the data was 0.0015% of the wall surface area per year. The coverage density was estimated based on information in EPA's Wall Paint Exposure Model (US EPA, 2001).

As discussed above, the tracking flux (*TrackingFlux*) is parameterized based on information in Von Lindern et al. (2003) and Thatcher and Layton (1995). Von Lindern et al. (2003) measured the amount of particulate deposited on front mats in 276 houses in two locations near the Bunker Hill Superfund Site. The lead levels reported in the paper are expected to be high-end and are not expected to represent general population exposures. This approach assumes, however, that the rate of accumulation of dust on doormats is not strongly affected by the location and can be used to represent a national population of homes. A distribution was developed by combining the data in the two locations in the 1998 site-wide analysis and estimating a geometric mean and geometric standard deviation for the pooled data. The central tendency estimate is the average of the estimated distribution. In addition, Thatcher and Layton (1995) measured the difference between particulate accumulation in tracked and untracked areas in the home as well as the amount on the front mat. This approach assumes that 75% of the home will contain tracked dirt, and the other 25% consists of corners or other less accessible areas in which people do not walk as frequently. Based on this assumption and the information about the amount of mass on the front mat, the tracked areas of the home, and the untracked areas of the home in Thatcher and Layton (1995), 10% of mass on shoes remains on the front mat (*MatFrac*) and 90% is carried into the homes. Such an assumption may be particularly reasonable in homes with children, as children are less likely than adults to wipe their feet carefully as they enter the home. Previous assessments have used different assumptions. The DIRT model (Johnson, 2008) assumed that the mass capture on the mat in the von Lindern study represented the total mass entering the home. For that model, a range of 50-300 mg/day was reported, and a mass flux of 200 mg/day was assumed for urban environments. This is lower than the average of approximately 1,100 mg/day in the current approach. As will be discussed below, however, this higher mass flux is more in agreement with the relative contribution to dust from outdoor soil reported in Adgate et al. (1998) and the average organic fraction in dust.

Cleaning efficiency (*CE*) has been found to vary according to the type of flooring (carpeting versus hard floor) and the total amount of lead on the floor (lower efficiencies for very low lead loadings, due to electrostatic forces attracting the particles to the floor or burial of lead deep into carpet, and higher efficiencies for higher lead loadings). The Environmental Field Sampling Study (EFSS), Volume I: Table 8D-3 (USEPA, 1997b) provides pre- and post-cleaning lead loading estimates from a house with hard floors that was subject to a renovation activity and post-activity cleaning. Thus, these estimates likely are higher than routine cleaning efficiencies

in a house where no renovation (and no associated elevated lead loading) has occurred. The selected value for *CE* (12.5% removal with each cleaning) represents an approximate midpoint in the lowest lead loading range in the study. These values are similar to values found by Ewers et al. (1994) and Clemson Environmental Technologies Laboratory (2001) for cleaning efficiencies on a carpeted floor after a renovation activity and after three previous cleaning iterations (so that much of the renovation-related lead loading had already been removed and the cleaning was similar to a routine cleaning). The range of efficiency in the literature varies widely. Bero et al. (1997) reported efficiencies of 50% for carpeted areas and 95% for hard floors, representing high-end estimates of efficiency. Roberts et al. (1994), as cited in Qian et al. (2008), reported efficiencies of only 5-10% in older carpets after lead dust exposure. In addition, Ewers et al. (1994) reported that cleaning must be thorough and be carried out for 6 m<sup>2</sup>/min to ensure removal of more than 70% of dust from carpets. Qian et al. (2008) assumed efficiencies of 5% based on a lower vacuuming rate of 1 m<sup>2</sup>/min, making the assumption that the 6 m<sup>2</sup>/min vacuuming rate is rarely achieved in practice.

Cleaning frequency (*CF*) represents a particularly sensitive variable, as will be discussed in section A.2.3. Self-reported cleaning frequency information was listed in the Exposure Factors Handbook (USEPA, 1997a) for 4,663 U.S. households. The respondents were asked to answer whether they swept or vacuumed nearly every day, three to five times a week, once or twice a week, once or twice a month, less often, or never. Table A-4 lists the data reported in the survey, and the respondents who reported they never cleaned or did not know were not used in the analysis. An upper bound was assigned to each bin and a geometric mean and geometric standard deviation for the overall data were estimated by calculating the distribution that minimized the squared errors between the actual and predicted cumulative probability distributions. The central tendency estimate is the average frequency in the calculated distribution. This value may indicate more cleanings than are realistic, since the data were self-reported; however, this dataset represents the most reliable one that could be located in the literature.

Overall, the selected cleaning efficiency may represent a value toward the lower bound of available values while the average cleaning frequency may be on the higher end (that is, fewer days between cleanings). This observation may reflect the fact that cleanings that occur more often may not be as thorough and may result in lower efficiencies. One way to cast the overall cleaning removal within the context of other models is to examine the cleaning transfer coefficient, which is defined as the cleaning efficiency divided by the days between cleanings. Table A-5 presents information comparing the cleaning removal rate from the current approach model to other models in the literature. Overall, the cleaning removal rate is on the low end of the literature values but is within the range of available values. The table also highlights the wide uncertainty and/or variability associated with this variable. The approach model attempts to address this variability by sampling the cleaning frequency distribution.

Emissions rates for the generation of particulate due to cooking were taken from the “Indoor Air Quality: Residential Cooking Exposures” final report (State of California’s Air Resources Board (CARB, 2001)). Experiments in the CARB study included both cooking episodes and oven cleaning; these were separated and oven cleaning was not included in the analysis. The cooking episodes tested tended to include fairly labor-intensive cooking activities such as frying and broiling meat, and the tests were performed on both electric and gas stoves and ranges. A

lognormal distribution was estimated by weighting each experimental cooking test equally to calculate the geometric mean and geometric standard deviation of emissions rates.

Emission rates due to the formation of human dander were taken from Gilbert (2003), who reported that the average human generates 1.5 grams of dander per day. The 2001 RECS (USDOE, 2001) was used to determine that the average U.S. household has 2.2 people in it. This number was rounded to three and multiplied by the amount of dander generated by each person per day. In addition, information from the CHAD database indicated that people tend to spend 2/3 of their time in the home and 1/3 outside the home on average. Thus, it was assumed that only 2/3 of the dander was emitted in the home. The final estimate, then, incorporates these three assumptions.

The assumption was made that the household members do not smoke in their home. A future refinement to the model could include distributions of smoking generation rates based on the frequency of smoking and assumptions about the number of smokers who smoke in their home as opposed to outdoors.

Finally, the outdoor air particulate rate was determined by examining PM<sub>10</sub> data from particulate monitors in the AQS monitoring network (US EPA, 2010). Data from 1997 were used to match the calibration data sets (see section A.2.2). In general, the particulate mass does not vary as strongly from location to location as the lead mass in the particulate. Thus, the model uses only a central tendency estimate for the particulate concentration based on the average annually-averaged concentration across the AQS monitors.

**Table A-3. Input Values for the Mechanistic Model**

| Variable               | Variable Name                                     | Units                          | Central Tendency Value | Geometric Mean | Geometric Standard Deviation | Source   |
|------------------------|---|--------------------------------|------------------------|----------------|------------------------------|--|
| <i>V</i>               | House Volume                                      | m <sup>3</sup>                 | 507                    | 390.5          | 2.06                         | US DOE (2001)  |
| <i>FloorLoading</i>    | Floor area per unit volume                        | m <sup>2</sup> /m <sup>3</sup> | 0.36                   | N/A            | N/A                          | US EPA (1997a)   |
| <i>WallLoading</i>     | Wall area per unit volume                         | m <sup>2</sup> /m <sup>3</sup> | 0.98                   | N/A            | N/A                          | US EPA (1997a)   |
| <i>AER</i>             | Air Exchange Rate                                 | h <sup>-1</sup>                | 0.63                   | N/A            | N/A                          | US EPA (1997a)   |
| <i>P</i>               | Penetration Efficiency                            | unitless                       | 1                      | N/A            | N/A                          | Thatcher and Layton (1995)   |
| <i>D</i>               | Deposition Rate                                   | h <sup>-1</sup>                | 0.65                   | N/A            | N/A                          | Value for PM10, US EPA (1997a), adapted from Wallace (1996)                                    |
| <i>R</i>               | Resuspension Rate                                 | h <sup>-1</sup>                | 1.4E-04                | N/A            | N/A                          | Qian et al. (2008)   |
| <i>ChipFraction</i>    | Fraction of wall area that flakes per year        | year <sup>-1</sup>             | 1.50E-05               | N/A            | N/A                          | Calibrated   |
| <i>CoverageDensity</i> | Paint Coverage Density                            | g/m <sup>2</sup>               | 1.25E+02               | N/A            | N/A                          | Estimated from paint density and EPA Wall Paint Exposure Model coverage default (US EPA, 2001) |
| <i>TrackingRate</i>    | Tracking Rate                                     | g/day                          | 1.21E-02               | 7.89E-02       | 2.52                         | Von Lindern et al. (2003)  |
| <i>MatFrac</i>         | Fraction of tracked material remaining on the mat | unitless                       | 0.1                    | N/A            | N/A                          | Estimated based on data in Thatcher and Layton (1995)  |
| <i>CE</i>              | Cleaning Efficiency                               | unitless                       | 0.125                  | N/A            | N/A                          | Estimated based on data in Battelle Memorial Institute (1997)                                  |
| <i>CF</i>              | Cleaning Frequency                                | days between cleanings         | 3.5                    | 3.27           | 1.78                         | US EPA (1997a)   |
| <i>CookingRate</i>     | Cooking Rate                                      | g/day                          | 0.35                   | N/A            | N/A                          | CARB (2001)  |
| <i>DanderRate</i>      | Dander Rate                                       | g/day                          | 3.015                  | N/A            | N/A                          | Estimated from information in Gilbert (2003)   |
| <i>SmokingRate</i>     | Smoking Rate                                      | g/day                          | 0                      | N/A            | N/A                          | Assumption   |
| <i>PartAir</i>         | Outdoor Air Particulate Concentration             | g/m <sup>3</sup>               | 2.36E-05               | N/A            | N/A                          | Based on analysis of AQS data (US EPA, 2010)   |

**Table A-4. Cleaning Frequency Data from the Exposure Factors Handbook**

| Frequency                  | Number Of Respondents | Percentage |
|----------------------------|-----------------------|------------|
| Nearly Every Day           | 921                   | 20%        |
| Three to Five Times a Week | 1108                  | 24%        |
| Once or Twice a Week       | 2178                  | 47%        |
| Once or Twice a Month      | 373                   | 8%         |
| Less Often                 | 48                    | 1%         |
| Never                      | 10                    | 0%         |
| Did Not Know               | 25                    | 1%         |

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**Table A-5. Comparison of Cleaning Transfer Coefficients in Mass Balance Models**

|                          | Cleaning Efficiency (unitless) | Days Between Cleanings (d) | Transfer Coeff (d <sup>-1</sup> ) |
|--------------------------|--------------------------------|----------------------------|-----------------------------------|
| Layton and Beamer (2009) | N/A                            | N/A                        | 5.30E-03                          |
| Qian et al. (2008)       | 0.05                           | 7                          | 7.14E-03                          |
| <b>Approach Model</b>    | <b>0.125</b>                   | <b>2.5</b>                 | <b>5.00E-02</b>                   |
| Johnson (2008)           | 0.725                          | 14                         | 5.18E-02                          |

2

### 3 A.2.2 Sensitivity Analysis

4 In order to determine the variables' values to which the model predictions are most sensitive, a  
5 preliminary sensitivity analysis was carried out. First, the media concentrations and other  
6 sampled variables were set to their mean values for the HUD dataset (cit.). Then, each variable  
7 was separately increased by 5% to determine the percent change in the floor loading, the floor  
8 concentration, and the slope. The percent changes were then divided by the percent change in  
9 the input (5%) to derive the elasticities. Comparison of the absolute value of elasticities across  
10 the different variables provides information about the variables to which the model is most  
11 sensitive.

12 Table A-6 shows the elasticities for each variable, where the table is sorted in decreasing order  
13 by the absolute value of the slope elasticities. None of the elasticities is greater than 1, indicating  
14 that changing a variable by 5% changes the slope by less than +/- 5%. The model is most  
15 sensitive to the cleaning frequency, the floor loading, the house volume, and the cleaning  
16 efficiency. To date, the model samples the cleaning frequency, but not the other three variables.  
17 The literature does not currently have reliable information to allow building a distribution of  
18 cleaning efficiencies. The preliminary sensitivity analysis, however, suggests that the model  
19 should sample both house volume and floor area loading in a future implementation in order to  
20 capture the variability in these variables. The model also displays moderate sensitivity to the  
21 dander generation rate, the fraction of material staying on the floor mat, the soil tracking rate, the  
22 deposition rate, and the air exchange rate.

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**Table A-6. Elasticities for Each Variable in the Model**

| Variable        | Variable Description                              | Floor Loading | Floor Concen. | Slope        |
|-----------------|---|---------------|---------------|--------------|
| CF              | Cleaning Frequency                                | 0.97          | 0.00          | <b>0.97</b>  |
| FloorLoading    | Floor Area Loading                                | -0.95         | 0.00          | <b>-0.95</b> |
| V               | House Volume                                      | -0.30         | 0.66          | <b>-0.93</b> |
| CE              | Cleaning Efficiency                               | -0.92         | 0.00          | <b>-0.92</b> |
| DanderRate      | Dander Rate                                       | 0.00          | -0.52         | <b>0.53</b>  |
| MatFrac         | Fraction of tracked material remaining on the mat | -0.33         | 0.07          | <b>-0.40</b> |
| TrackingRate    | Tracking Rate                                     | 0.31          | -0.06         | <b>0.38</b>  |
| D               | Deposition Rate                                   | 0.10          | -0.21         | <b>0.31</b>  |
| AER             | Air Exchange Rate                                 | 0.07          | 0.36          | <b>-0.29</b> |
| CookingRate     | Cooking Rate                                      | 0.00          | -0.06         | <b>0.06</b>  |
| R               | Resuspension Rate                                 | -0.03         | 0.00          | <b>-0.03</b> |
| PartAir         | Outdoor Air Particulate Concentration             | 0.00          | -0.03         | <b>0.03</b>  |
| WallLoading     | Wall area per unit volume                         | 0.52          | 0.52          | <b>0.00</b>  |
| ChipFraction    | Fraction of wall area that flakes per year        | 0.52          | 0.52          | <b>0.00</b>  |
| CoverageDensity | Paint Coverage Density                            | 0.00          | 0.00          | <b>0.00</b>  |
| PbAirConcen     | Ambient Air Lead Concentration                    | 0.17          | 0.17          | <b>0.00</b>  |
| PbSoilConcen    | Soil Lead Concentration                           | 0.31          | 0.31          | <b>0.00</b>  |
| PbPaintConcen   | Paint Lead Concentration                          | 0.52          | 0.52          | <b>0.00</b>  |

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2 **A.2.3 Calibration and Comparisons to Datasets**

3 Two datasets were identified for use in calibrating and evaluating the model for residences. The  
 4 first is the HUD survey of lead in homes (USEPA 1998). This survey provides paint  
 5 concentrations (as XRF readings), yard soil concentrations, indoor dust lead loading wipe  
 6 samples and indoor dust lead concentrations for 284 homes. These homes, when combined with  
 7 their respective weights, are intended to be nationally representative of lead levels in the US  
 8 housing stock in 1997.

9 In order to compare the model predictions to the survey results, the AQS data were used to  
 10 estimate the distribution of lead in total suspended particles (TSP) in 1997 (US EPA, 2010).  
 11 Available lead monitoring results were averaged to give yearly averages and a lognormal  
 12 distribution was developed based on the range of values across the different monitors. In  
 13 addition, distributions of paint concentration and soil concentration were developed from the  
 14 HUD data from homes built before 1980. The model was then run under the assumption of three  
 15 different cleaning frequencies (once a week, twice a week, and twice a month) based on the  
 16 range of cleaning frequencies in the Exposure Factors Handbook (US EPA, 1997a). To generate  
 17 each of the 100 model points, the soil, paint, and air concentration distributions were sampled to  
 18 generate a combination of estimates, and the model equations were applied to calculate the floor  
 19 loading and the slope. Figure A-3 shows the lead loadings and corresponding concentrations for  
 20 the HUD data and the model predictions. The regression equation discussed in Section A.1 is  
 21 also shown for reference.

22 For a given cleaning frequency, the mechanistic model predictions fall in a straight line defined  
 23 by the slope equation above. Because this equation does not depend on the soil, paint, and air

1 concentrations and because nothing else was sampled in the development of the figure, the slope  
2 is constant for a given cleaning frequency. The slope tends to decrease in homes in which  
3 cleaning occurs less frequently. The national average cleaning frequency in the Exposure  
4 Factors Handbook is approximately two cleanings per week; thus, the paint flaking fraction  
5 variable (*ChipFraction*) was adjusted until the slope was in good agreement with the regression  
6 line for loadings up to the 75<sup>th</sup> percentile loading (a value of approximately 17.3  $\mu\text{g}/\text{ft}^2$ ). Note  
7 that the other two cleaning frequencies represent high and low bounds estimates for the  
8 population (cleaning every day represents the 2<sup>nd</sup> percentile while cleaning once every two  
9 weeks represents the 99.5<sup>th</sup> percentile from the estimated cleaning frequency distribution) and  
10 they bound the majority of the loading and concentration data points.

11 The model predicts a straight line for a given cleaning frequency, while the regression suggests a  
12 nonlinear relationship. One possible interpretation of this discrepancy is that most of the higher  
13 loadings likely occur in homes which are vacuumed less often. Thus, as one moves along the  
14 loading axis, a change in cleaning frequency leads to a change in the slope of the loading-  
15 concentration relationship.

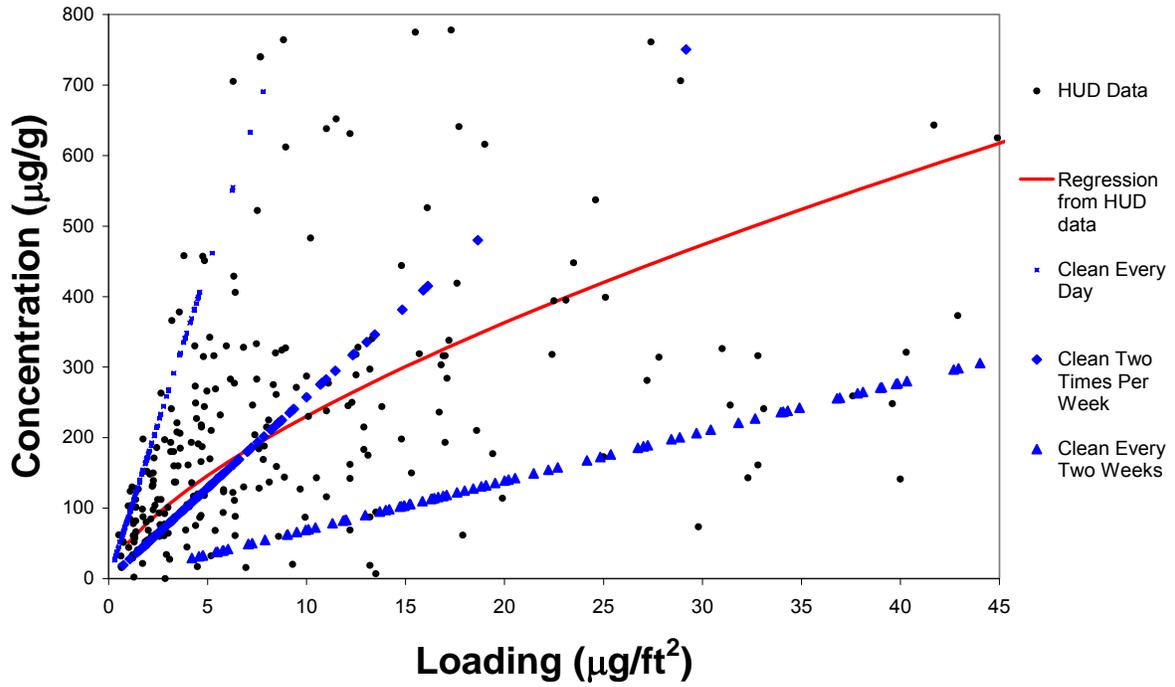
16 Once this initial calibration step was complete, the model was run again by sampling additional  
17 variables where distributions existed; thus, in addition to the soil, paint, and air concentrations,  
18 the soil tracking rate and cleaning frequency were also sampled. The resulting model points are  
19 shown along with the raw HUD data in Figure A-4. These model values provide a spread across  
20 the actual data. In order to quantify the model performance, Table A-7 provides a comparison of  
21 the average and median loadings and concentrations. The model tends to underpredict the mean  
22 loadings and concentrations; the means are more affected by the outliers, suggesting that the  
23 central tendency values used for most variables may not be sufficient to capture the very high  
24 loadings and concentrations. The model is able to capture the median loadings and  
25 concentrations, however, which still reflect the distribution, but are not as affected by outliers.

26 Table A-8 compares model metrics to values found in the literature for data or from other  
27 models. Adgate et al. (1998) provided estimates of the fraction of the loading arising from the  
28 air, soil, and paint sources in homes in Jersey City, NJ. The model tends to predict more lead  
29 arising from paint sources and less from soil sources than in the Adgate study. The Jersey City  
30 homes in the Adgate study, however, tended to be in urbanized areas with higher average soil  
31 concentrations than in the nationally-representative HUD dataset. Also shown is the average  
32 indoor/outdoor air ratio in 35 California homes for  $\text{PM}_{10}$  from Colome et al. (1992). The model  
33 predicts a ratio very close to this value, which provides further support to the fact that the model  
34 coefficients are not merely tuned, but may be reflecting the actual physical processes at work in  
35 the homes. The model predicts that about 66% of indoor dust mass arises from indoor sources of  
36 organic material (e.g., cooking, human dander). After analyzing the dust in four homes in  
37 England, Allott et al. (1994) concluded that 42% +/- 17% arose from organic sources. This  
38 suggests the model prediction is within the range found in the four homes in the study and lends  
39 support to the relative contribution from soil, paint, air, and indoor sources to indoor dust.

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Figure A-3. Modeled Loading-to-Concentration Relationships for Three Different Cleaning Frequencies



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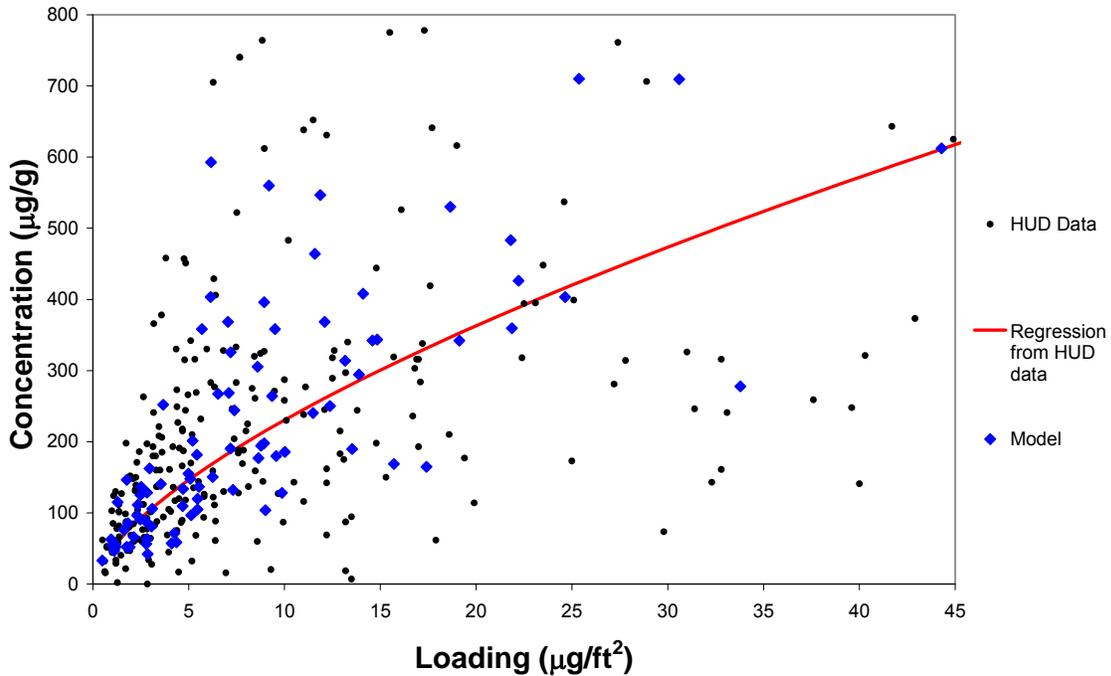
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Figure A-4. Modeled Loading and Concentration Values Using HUD Air, Paint, and Soil Distributions and Distributions for Soil Tracking and Cleaning Frequency



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**Table A-7. Comparison Between Modeled and Actual Loadings and Concentrations**

|          | Mean Load | Mean Concen | Median Load | Median Concen |
|----------|-----------|-------------|-------------|---------------|
| HUD Data | 21        | 559         | 7.4         | 201           |
| Model    | 13        | 336         | 7.3         | 188           |

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**Table A-8. Comparison Between Modeled and Actual Loadings and Concentrations**

|            | % Air            | % Soil           | % Paint          | Indoor / Outdoor Air Ratio | % Indoor Dust from Organic Sources |
|------------|------------------|------------------|------------------|----------------------------|------------------------------------|
| Literature | 17% <sup>1</sup> | 49% <sup>1</sup> | 34% <sup>1</sup> | 0.7 <sup>2</sup>           | 42% +/- 17% <sup>3</sup>           |
| Model      | 38%              | 13%              | 49%              | 0.63                       | 66%                                |

<sup>1</sup> From Adgate et al. (1998)

<sup>2</sup> From Colome et al. (1992)

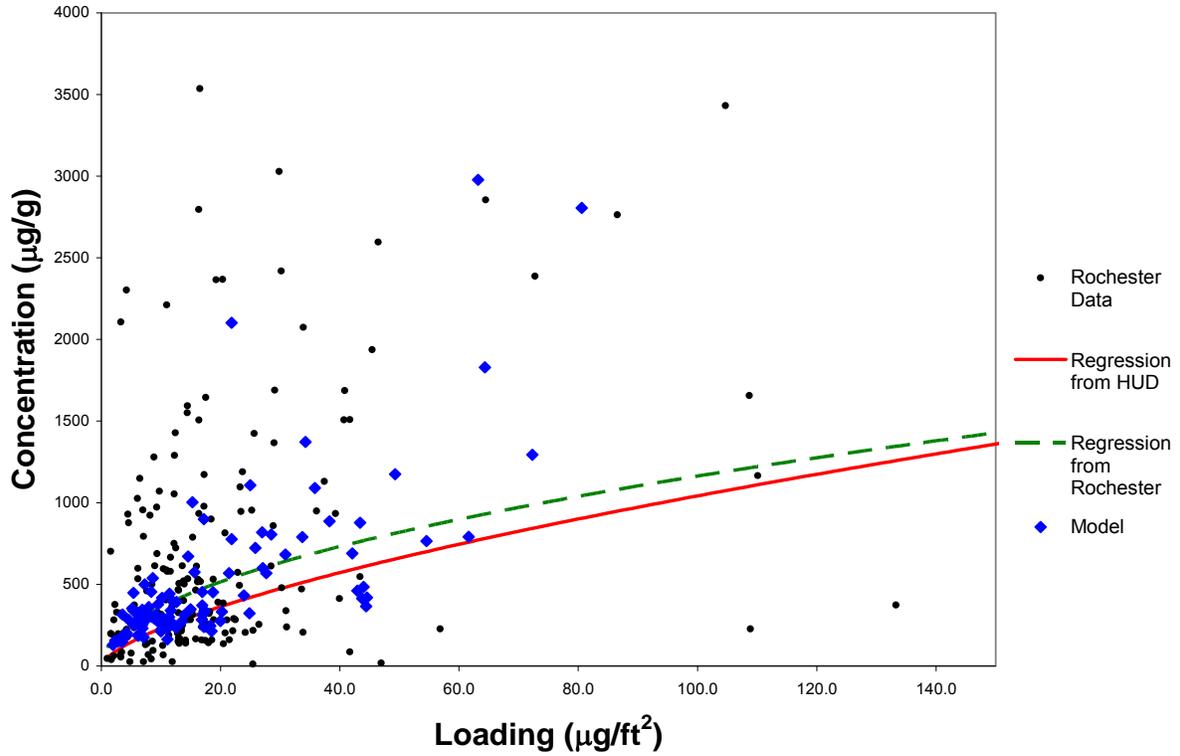
<sup>3</sup> From Allott et al. (1994)

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2 Once the calibration was complete, the model was applied to a second dataset as a further model  
3 evaluation. Lanphear et al. (1998) collected data for 205 children in Rochester, NY. As part of  
4 the blood lead evaluation, they collected wipe lead dust loading samples, lead concentration  
5 samples, indoor XRF lead paint concentrations, and play yard and house perimeter lead soil  
6 samples. Samples were collected in multiple areas and a composite was estimated as the average  
7 or median sample value. Distributions were generated from the lead paint concentrations and  
8 play yard soil lead concentrations for use in the model. It was assumed that the play yard soil  
9 would be more readily tracked into the home than the house perimeter soil. The AQS  
10 monitoring network was used to calculate lead concentrations in the ambient air. A distribution  
11 was generated by finding the monthly average concentrations for data from 1993-1996 and  
12 finding the geometric mean and geometric standard deviation. The model was then applied to  
13 the dataset with no other modifications. The lead air concentration, lead soil concentration, lead  
14 paint concentration, soil tracking rate, and cleaning frequency were all sampled and modeled for  
15 100 realizations and compared to the median of the floor lead loading and concentration  
16 estimates. Figure A-5 provides a comparison between the modeled and actual data. As in the  
17 HUD dataset, the spread and pattern of modeled data are consistent with the actual data. Note  
18 that the spread of the data is larger in the Rochester data than in the HUD data, likely due to  
19 much larger average soil concentrations. Also shown for reference is the regression line  
20 calculated from the HUD data and the regression line calculated directly from the Rochester  
21 data. The regression lines predict similar relationships at higher loadings, but differ by 25-50%  
22 for loadings between 10 and 40  $\mu\text{g}/\text{ft}^2$ .

23 Table A-9 compares the modeled and actual means and medians along with the source  
24 contribution percentages and outdoor/indoor air ratios. Overall, the model does well at  
25 predicting the medians, although it tends to underpredict the means as in the HUD dataset. Table  
26 A-10 compares other model metrics to the values in the literature. The source percentages are  
27 more similar to the Adgate data (1998), perhaps because the Rochester homes are more  
28 comparable with the Adgate Jersey City homes; however, the model still tends to contribute  
29 more from paint and less from soil than the Adgate data suggest. The indoor/outdoor ratio is still  
30 within range of the mean value from Colome et al. (1992). The percentage of dust mass arising  
31 from indoor sources is the same as in the HUD model, since this value does not rely on any of  
32 the lead media concentration values.

Figure A-5. Modeled Loading and Concentration Values Using Rochester Air, Paint, and Soil Distributions and Distributions for Soil Tracking and Cleaning Frequency



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**Table A-9. Comparison Between Modeled and Actual Loadings and Concentrations**

|                | Mean Load | Mean Concen | Median Load | Median Concen |
|----------------|-----------|-------------|-------------|---------------|
| Rochester Data | 21        | 776         | 14          | 370           |
| Model          | 20        | 590         | 13          | 342           |

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**Table A-10. Comparison Between Modeled and Actual Loadings and Concentrations**

|            | % Air            | % Soil           | % Paint          | Indoor / Outdoor Air Ratio | % Indoor Dust from Organic Sources |
|------------|------------------|------------------|------------------|----------------------------|------------------------------------|
| Literature | 17% <sup>1</sup> | 49% <sup>1</sup> | 34% <sup>1</sup> | 0.7 <sup>2</sup>           | 42% +/- 17% <sup>3</sup>           |
| Model      | 16%              | 27%              | 57%              | 0.63                       | 66%                                |

<sup>1</sup> From Adgate et al. (1998)

<sup>2</sup> From Colome et al. (1992)

<sup>3</sup> From Allott et al. (1994)

1

2 **A.3 Strengths and Limitations of the Loading-Concentration Conversion**  
 3 **Models**

4 As discussed in Section 2.3.2, each of these two alternative methods to convert the loadings to  
 5 concentrations has strengths and limitations. The regression equation is based on a nationally-  
 6 representative dataset with sufficient samples across different housing vintages, outdoor soil  
 7 concentrations, and indoor paint concentrations. The regression equation is most reliably applied  
 8 in the range of loadings and concentrations seen in the original dataset, and the hazard standard  
 9 is anticipated to fall within that range. The equation is specific to residences, however, and  
 10 cannot be easily extended to public and commercial buildings (see Section 3.2.3). In addition,  
 11 the regression equation does not allow any incorporation of variability due to the difference in  
 12 physical attributes and cleaning patterns among homes. The underlying data show a wide spread  
 13 across the loading-concentration parameter space, indicating wide house-to-house variability (see  
 14 Appendix A).

15 The mechanistic model, on the other hand, allows for extension of the model to public and  
 16 commercial buildings, provided the physical processes are described adequately and the proper  
 17 input values can be developed. Because the public/commercial buildings tend to be larger, more  
 18 people come in and out of the buildings daily (thus introducing more dander to the indoor  
 19 environment and diluting the indoor dust), and the cleaning patterns are different, these buildings  
 20 can be expected to have a very different loading-to-concentration relationship than houses.  
 21 However, the model assumes that the indoor environment is well-mixed and contains no  
 22 concentration gradients; thus, it can be applied to any portion of the public/commercial building  
 23 where this assumption is valid. The mechanistic model also allows for the loading to  
 24 concentration conversion to incorporate house-to-house variability. The model is subject to  
 25 uncertainty, however, because of the relatively simple form of the physical equations and the  
 26 absence of information about some of the variable inputs. The model has been calibrated against  
 27 the HUD dataset and then compared to one additional dataset, and the model is expected to  
 28 return reasonable estimates for the national population in the range of the hazard standard. There  
 29 currently is no relationship between window sill loading and concentration, however, and unless  
 30 such a slope is developed, the same slope as used for the floor dust would have to be used in  
 31 developing the window sill hazard standard.

32 In addition, the mechanistic model uses the steady state solution to the model equations. One  
 33 assumption is made in the development of these equations, however, which affects the solution.  
 34 When the steady state equations are solved, an assumption is made that routine cleaning happens

1 continuously at a rate equal to the cleaning frequency. In reality, however, the cleaning occurs in  
2 discrete episodes once per cleaning cycle. This assumption introduces some error into the slope,  
3 loading, and concentration estimates, and this error increases with increasing numbers of days  
4 between cleaning. Table A-11 shows a representative sample of the slope and loadings under the  
5 assumption of episodic and continuous cleaning for ten of the 200 model realizations. For  
6 cleaning every two weeks, the error in the slope is up to 14.5%; however, at the average cleaning  
7 frequency (about two cleanings per week), the error is only an average of 7.0% (maximum of  
8 9.5%). The errors in the loadings are comparable, and the errors in the concentrations are only  
9 an average of 0.5% (maximum of 0.7%). Thus, this assumption, which is necessary from a  
10 practical standpoint in the development of the hazard standard in order to avoid numerous  
11 iterations of the model, introduces reasonable error in the region of anticipated cleaning  
12 frequencies.

13 While attempts have been made to take into account variability across homes by sampling some  
14 of the input parameters, no attempt has been made to account for variability within a home.  
15 Unlike the DIRT model (Johnson, 2008), which predicts gradients across floors and carpets, the  
16 model treats the home as a uniform environment. Differences across carpets and floors and  
17 between high traffic areas and less accessible areas are not accounted for in the model, and the  
18 assumption is made that the model captures the mean characteristics of the heterogeneous home.

**Table A-11. Representative Realizations Demonstrating the Error When Considering Continuous Cleaning Compared to Episodic Clean**

| Realization | Outdoor Air Concn. (µg/m3) | Soil Concn. (µg/g) | Paint Concn. (µg/g) | Tracking (g/day) | Clean. Freq. (days between clean.) | Floor Loading, Episodic Clean. | Floor Concn, Episodic Clean. | Slope, Episodic Clean. | Floor Loading, Contin. Clean. | Floor Concn. Contin. Clean. | Slope, Contin. Clean. | % Error in Load. | % Error in Concn. |
|-------------|----------------------------|--------------------|---------------------|------------------|------------------------------------|--------------------------------|------------------------------|------------------------|-------------------------------|-----------------------------|-----------------------|------------------|-------------------|
| 1           | 9.39E-02                   | 1.39E+02           | 1.11E+00            | 9.50E-02         | 2.38E+00                           | 6.04E+00                       | 2.69E+02                     | 2.25E-02               | 6.45E+00                      | 2.67E+02                    | 2.42E-02              | 6.8%             | -0.5              |
| 5           | 4.12E-02                   | 6.80E+01           | 2.10E+00            | 1.78E-02         | 3.74E+00                           | 7.93E+00                       | 3.08E+02                     | 2.58E-02               | 8.43E+00                      | 3.06E+02                    | 2.76E-02              | 6.3%             | -0.7              |
| 9           | 4.32E-03                   | 9.61E+00           | 2.53E+01            | 1.20E-01         | 9.47E-01                           | 1.80E+01                       | 1.81E+03                     | 9.96E-03               | 1.92E+01                      | 1.80E+03                    | 1.07E-02              | 6.5%             | -0.5              |
| 13          | 2.50E-02                   | 4.41E+01           | 8.20E-01            | 1.33E-01         | 2.52E+00                           | 2.87E+00                       | 1.06E+02                     | 2.70E-02               | 3.06E+00                      | 1.06E+02                    | 2.89E-02              | 6.5%             | -0.4              |
| 17          | 4.82E-02                   | 7.79E+01           | 1.69E+00            | 2.79E-01         | 5.72E+00                           | 1.44E+01                       | 1.69E+02                     | 8.49E-02               | 1.53E+01                      | 1.69E+02                    | 9.05E-02              | 6.3%             | -0.3              |
| 21          | 2.04E-02                   | 3.69E+01           | 9.95E-01            | 3.10E-02         | 3.15E+00                           | 3.28E+00                       | 1.42E+02                     | 2.32E-02               | 3.49E+00                      | 1.41E+02                    | 2.48E-02              | 6.6%             | -0.6              |
| 25          | 3.06E-03                   | 7.11E+00           | 2.96E-01            | 5.28E-02         | 1.70E+00                           | 4.66E-01                       | 3.34E+01                     | 1.39E-02               | 4.97E-01                      | 3.32E+01                    | 1.50E-02              | 6.6%             | -0.6              |
| 29          | 2.41E-02                   | 4.27E+01           | 9.28E-01            | 7.75E-02         | 2.05E+00                           | 2.30E+00                       | 1.26E+02                     | 1.83E-02               | 2.46E+00                      | 1.25E+02                    | 1.96E-02              | 6.7%             | -0.5              |
| 33          | 1.49E-01                   | 2.07E+02           | 6.02E-01            | 4.05E-02         | 3.18E+00                           | 8.78E+00                       | 3.60E+02                     | 2.44E-02               | 9.34E+00                      | 3.58E+02                    | 2.61E-02              | 6.4%             | -0.6              |
| 37          | 4.34E-01                   | 5.24E+02           | 1.38E+00            | 5.50E-02         | 1.80E+00                           | 1.44E+01                       | 9.76E+02                     | 1.48E-02               | 1.54E+01                      | 9.70E+02                    | 1.59E-02              | 6.9%             | -0.6              |
| 41          | 3.62E-02                   | 6.08E+01           | 8.21E-01            | 1.27E-01         | 1.93E+00                           | 2.63E+00                       | 1.29E+02                     | 2.04E-02               | 2.80E+00                      | 1.28E+02                    | 2.18E-02              | 6.4%             | -0.4              |
| 45          | 9.97E-03                   | 1.98E+01           | 1.26E+00            | 5.72E-02         | 6.35E+00                           | 6.67E+00                       | 1.33E+02                     | 5.02E-02               | 7.08E+00                      | 1.32E+02                    | 5.36E-02              | 6.2%             | -0.6              |
| 51          | 2.38E-02                   | 4.22E+01           | 3.69E+00            | 1.46E-01         | 1.50E+00                           | 4.80E+00                       | 2.91E+02                     | 1.65E-02               | 5.24E+00                      | 2.90E+02                    | 1.81E-02              | 9.1%             | -0.4              |
| 55          | 7.05E-02                   | 1.08E+02           | 6.93E-01            | 2.47E-02         | 1.95E+00                           | 3.10E+00                       | 2.19E+02                     | 1.42E-02               | 3.30E+00                      | 2.17E+02                    | 1.52E-02              | 6.7%             | -0.7              |
| 59          | 7.43E-02                   | 1.13E+02           | 8.81E-01            | 1.26E-01         | 1.36E+00                           | 2.97E+00                       | 2.05E+02                     | 1.45E-02               | 3.16E+00                      | 2.04E+02                    | 1.55E-02              | 6.5%             | -0.5              |
| 63          | 2.70E-01                   | 3.48E+02           | 8.28E-01            | 2.70E-02         | 8.63E+00                           | 3.76E+01                       | 6.42E+02                     | 5.86E-02               | 3.99E+01                      | 6.38E+02                    | 6.25E-02              | 6.1%             | -0.6              |
| 67          | 1.68E-02                   | 3.12E+01           | 2.12E+00            | 3.84E-02         | 3.03E+00                           | 5.52E+00                       | 2.39E+02                     | 2.31E-02               | 5.86E+00                      | 2.37E+02                    | 2.47E-02              | 6.2%             | -0.6              |
| 71          | 1.13E-01                   | 1.64E+02           | 2.74E+00            | 4.59E-02         | 4.44E+00                           | 1.66E+01                       | 4.85E+02                     | 3.42E-02               | 1.77E+01                      | 4.82E+02                    | 3.67E-02              | 6.5%             | -0.6              |
| 75          | 1.50E+00                   | 1.54E+03           | 1.43E+00            | 9.95E-02         | 6.89E+00                           | 1.77E+02                       | 2.80E+03                     | 6.31E-02               | 1.88E+02                      | 2.79E+03                    | 6.72E-02              | 6.1%             | -0.5              |
| 79          | 7.27E-02                   | 1.11E+02           | 3.63E+00            | 4.01E-02         | 8.42E+00                           | 3.00E+01                       | 4.95E+02                     | 6.06E-02               | 3.18E+01                      | 4.92E+02                    | 6.47E-02              | 6.1%             | -0.6              |
| 83          | 2.24E+00                   | 2.18E+03           | 9.50E-01            | 6.81E-03         | 2.94E+00                           | 9.48E+01                       | 4.89E+03                     | 1.94E-02               | 1.01E+02                      | 4.86E+03                    | 2.08E-02              | 6.4%             | -0.7              |
| 87          | 1.38E-03                   | 3.57E+00           | 2.60E+00            | 1.63E-01         | 5.21E+00                           | 9.80E+00                       | 1.66E+02                     | 5.89E-02               | 1.04E+01                      | 1.66E+02                    | 6.29E-02              | 6.3%             | -0.4              |
| 91          | 7.98E-01                   | 8.90E+02           | 4.50E+00            | 7.50E-01         | 5.79E+00                           | 2.00E+02                       | 1.17E+03                     | 1.71E-01               | 2.13E+02                      | 1.17E+03                    | 1.81E-01              | 6.1%             | -0.2              |
| 95          | 1.66E-01                   | 2.27E+02           | 6.24E-01            | 5.89E-02         | 2.83E+00                           | 9.01E+00                       | 3.85E+02                     | 2.34E-02               | 9.61E+00                      | 3.83E+02                    | 2.51E-02              | 6.7%             | -0.6              |
| 100         | 1.26E-01                   | 1.79E+02           | 1.25E+00            | 1.01E-01         | 2.29E+00                           | 7.48E+00                       | 3.36E+02                     | 2.22E-02               | 7.96E+00                      | 3.34E+02                    | 2.38E-02              | 6.4%             | -0.5              |

**A.4 Regression Relationship for Floor and Sill Dust Loadings**

The National Survey of Lead-Based Paint in Housing ("HUD Survey Data") was used to develop an empirical relationship between floor and window sill dust loadings. As discussed in Section A.1, in order to focus on the homes containing lead paint, only the data from the first three vintage categories were included. From the raw data, each floor and window sill dust loading was transformed by taking the natural log. Then, the regression was carried out using the untransformed variables and also the natural-log-transformed variables. Table A-12 shows the results of each regression.

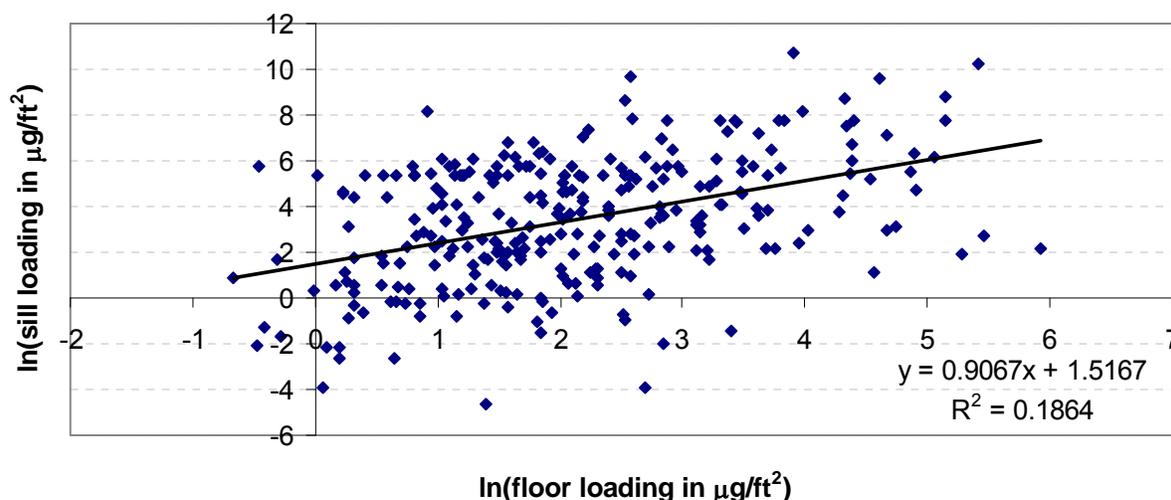
**Table A-12. Regression Analysis Results**

| Data                    | Variable  | Coefficient | Standard Error of Coefficient | t-stat | p-value | F-stat, p-level | Adjusted R2 |
|-------------------------|-----------|-------------|-------------------------------|--------|---------|-----------------|-------------|
| Untransformed           | Intercept | 203.8       | 219.6                         | 0.93   | 0.35    | 20.5,<br><0.001 | 0.064       |
|                         | Slope     | 21.7        | 4.8                           | 4.5    | <0.001  |                 |             |
| Natural-log-transformed | Intercept | 1.52        | 0.28                          | 5.44   | <0.001  | 64.6,<br><0.001 | 0.186       |
|                         | Slope     | 0.91        | 0.11                          | 8.04   | <0.001  |                 |             |

The data are positively skewed, and the regression analysis reveals that the log-transformed data appear more highly correlated, with a greater adjusted R<sup>2</sup>. Thus, the transformed relationship is chosen, and Figure A-6 shows the data and the regression equation. The equation relating the two loadings would then be

$$Sill = 4.56 \times Floor^{0.91}$$

**Figure A-6. Regression Relationship between Ln(Sill) vs Ln(Floor) for the HUD Data**



As an alternative method, Lanphear et al. (1998) collected data for 205 children in Rochester, collected in multiple locations and arithmetic and geometric averages were calculated. For the floor to sill relationship, the geometric means of floor and sill loadings were selected since they are not as susceptible to outliers within the house. As with the HUD data, regressions were performed on both the untransformed and natural-log-transformed variables. Table A-13 shows the results of each regression.

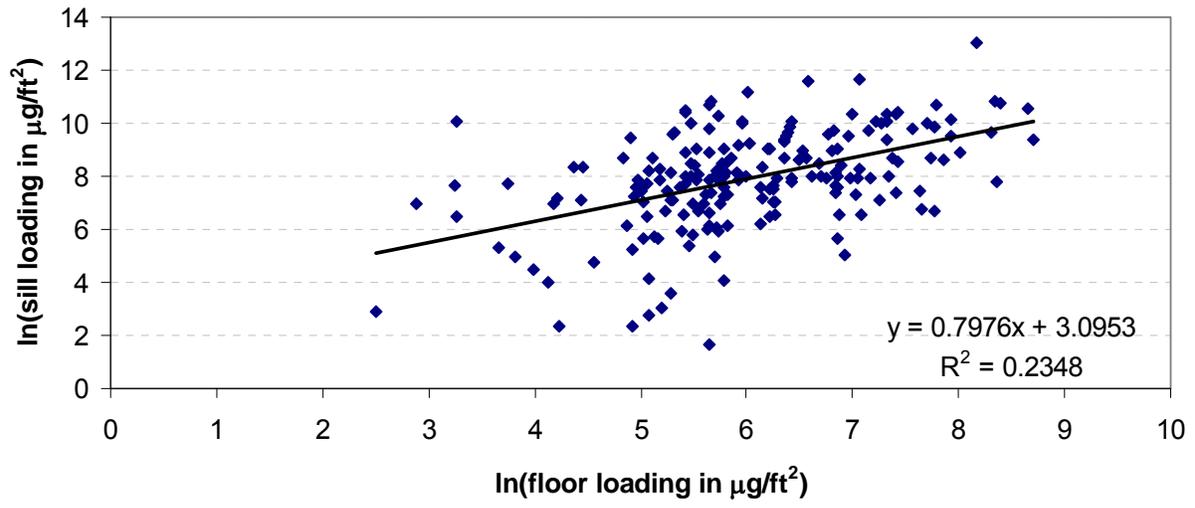
**Table A-13. Regression Analysis Results**

| Data                    | Variable  | Coefficient | Standard Error of Coefficient | t-stat | p-value | F-stat, p-level | Adjusted R2 |
|-------------------------|-----------|-------------|-------------------------------|--------|---------|-----------------|-------------|
| Untransformed           | Intercept | 2583.1      | 3034.5                        | 0.85   | 0.40    | 21.0, <0.001    | 0.094       |
|                         | Slope     | 11.1        | 2.4                           | 4.58   | <0.001  |                 |             |
| Natural-log-transformed | Intercept | 3.1         | 0.64                          | 4.86   | <0.001  | 58.9, <0.001    | 0.234       |
|                         | Slope     | 0.80        | 0.10                          | 7.68   | <0.001  |                 |             |

Again, the log-transformed analysis was selected since the variables appear more highly correlated (with a greater adjusted R<sup>2</sup>), and Figure A-7 shows the data and the regression equation. In this case, the correlation is slightly higher (R=0.48) and the equation relating sill to floor loading would be

$$Sill = 22.1 \times Floor^{0.80}$$

Figure A-7. Regression Relationship between Ln(Sill) vs Ln(Floor) for the Rochester Data



## A.5 References

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