A SUMMARY OF THE RELATIONSHIPS BETWEEN BLOOD LEAD AND LEAD-CONTAMINATED SOIL AND LEAD-CONTAMINATED DUST, AS REPORTED IN THE SCIENTIFIC LITERATURE

1.0 Introduction

Extensive regulatory and educational efforts undertaken since 1976 have dramatically reduced children's average blood-lead concentrations nationwide. The National Health and Nutrition Examination Surveys (NHANES) trace the health and nutritional status of the population. The results of the NHANES report that for children between the ages of 1 and 5 years, the geometric mean blood-lead concentration declined from 15.0 µg/dL in the NHANES II (1976-1980) study to 3.6 µg/dL in the NHANES III (1988-1991) study [1]. Despite the reduction, childhood lead exposure is still a problem. The first phase of the NHANES III study estimated that 8.9 % (approximately 1.7 million) of children between the ages of 1 and 5 nationally continue to have blood-lead concentrations above 10 µg/dL, the level of concern calling for community prevention measures as defined by the Centers for Disease Control and Prevention guidelines in 1991 [2].

During the past 20 years, studies have been conducted to determine the sources responsible for lead exposure in children. These studies initially emphasized exposure from lead in paint and leaded gasoline emissions, but increasingly have focused principally on two environmental media, residential dust and soil, often contaminated by these original sources. This emphasis derives from the assessment by most researchers in the area of childhood lead exposure that hand-to-mouth behavior represents the principal mechanism of exposure. The studies, therefore, constitute a significant body of epidemiological evidence on children's exposure to environmental lead in dust and soil.

Traditionally, the studies summarize the epidemiological evidence of lead exposure by reporting the associations between dust-lead or soil-lead levels and children's blood-lead concentrations, usually via regression relationships. The slope coefficients associated with the environmental media in these regression relationships characterize the estimated increase in blood-lead concentration per unit increase in the lead levels of the particular environmental media. If a common estimate of a slope coefficient for either soil or dust can be agreed upon it could be used to help develop hazard levels for environmental lead levels in soil and dust.

Dr. Kathryn Mahaffey of the Environmental Criteria and Assessment Office of EPA explored the possibility of finding common slope coefficient estimates in 1994 [3]. Her report considered the body of epidemiological evidence with the objective of reporting the range of estimated slope coefficients. This paper summarizes Mahaffey's report and updates it by including results from the recent Rochester Lead-In-Dust Study [4] and on-going Baltimore Repair and Maintenance Study [5].

2.0 Summary of Evidence

In her report, Dr. Mahaffey discusses the results of two separate statistical analyses providing quantitative estimates of the associations between children's blood-lead concentrations and the soil- and dust-lead levels in their surrounding residential environment. In both analyses, associations are presented as slope coefficients indicating change in lead concentrations of blood per change in lead levels of soil or dust.

The first analysis ("Phase 1") is summarized from Rust and Burgoon [7]. In their report, Rust and Burgoon calculated 'linearized slope coefficients' for blood lead to soil lead based on models published in the scientific literature. The calculated coefficients represent estimates of the predicted change in blood-lead concentration per change in environmental soil concentration at specified soil-lead concentrations. For purposes of this summary, similar calculations were performed to quantify the relationship between blood-lead concentration and dust lead concentration and/or loading, again based on models published in the scientific literature. The number of studies summarized is limited because of the varied reporting practices within the literature. A number of studies collected the relevant data, but did not report the appropriate regression equations. The specific variables fitted to blood in the published regressions also vary considerably, making comparison of the coefficients that are reported across studies difficult. Moreover, as many of the reported analyses utilized regression models that relate log-transformed blood-lead concentration to log-transformed soil- or dust-lead levels, a single slope coefficient cannot be reported for all soil- or dust-lead levels (i.e., the relationship between blood lead and dust or soil lead is not characterized by a straight line but by an exponential curve). To address this issue, linearized slope coefficients are calculated from the published coefficients and reported across a range of dust- or soil-lead levels.

The second analysis ("Phase 2") is summarized from Marcus and Elias [8]. In their report, Marcus and Elias reanalyze the data from seven studies (four of those considered by Rust and Burgoon) using a consistent model. The model used for each of these reanalyses is a nonlinear model, also called the log-additive model, of the form

$$\log(PbB) = \log(\beta_0 + \beta_1 \cdot PbS + \beta_2 \cdot PbD) \quad .$$

The slope parameters β_1 and β_2 relate blood lead to soil lead and dust lead, respectively. This model has the advantage of characterizing the relationship between blood-lead concentrations and dust- or soil-lead levels as straight lines. Marcus and Elias performed these analyses on two strata for each of the seven studies, the first was children between 12 and 35 months of age, the second was children between 36 and 84 months of age.

Since the preparation of Mahaffey's report, the results of two additional studies have been reported, the Rochester Lead-In-Dust Study ([4], [6]) and the preliminary pre-intervention results of the Baltimore Repair and Maintenance Study [5]. For both studies, linearized slope coefficients were calculated for a range of soil lead concentrations and dust lead levels in a

manner similar to Rust and Burgoon's treatment of other studies. Slope estimates similar to those reported by Marcus and Elias are not available for these studies as the appropriate model has not been fitted to the data.

Table 1 presents the *blood versus soil* results summarized by Mahaffey [3] as well as the Rochester Lead-in-Dust and Baltimore Repair and Maintenance results computed for this report. Specifically, for each identified study, Table 1 presents the observed range in blood-lead concentrations and soil-lead concentrations, the linearized slope coefficients and the slope coefficients reported by Marcus and Elias.

For each study in Table 1, the Rust and Burgoon results include a linearized slope estimate for a range of soil-lead concentrations (500 to 2000 ppm). In addition, the slope estimate and associated soil-lead concentration is reported for a range of potential blood-lead concentrations (2.5-30 µg/dL). Comparable results, calculated for this report, are reported for the Rochester Lead-in-Dust Study. The regression results utilized to derive the linearized slope estimates are based on data covering a specific range of blood-lead concentrations as well as a specific range of soil- or dust-lead levels. Extrapolation beyond the range of the data is dangerous especially when fitting an exponential function such as those fitted in most of the studies. Table 1, therefore, provides estimates only for particular soil concentrations within the range of the data. However, a few unrealistic estimates (indicated by an asterisk) are also included to demonstrate the range over which the linearized estimate procedure may be viable.

In contrast to the Rust and Burgoon results, the Marcus and Elias results for each study in Table 1 include a single estimated slope coefficient relating blood-lead and soil-lead. This is possible because of the form of the regression model used to reanalyze the data. The eighth column reports the results for children between 12 and 35 months of age, the ninth column reports the results for children between the ages of 36 and 84 months.

Table 2 presents *blood versus dust* results similar to the blood versus soil results described above. For each study, Table 2 presents the observed range in blood-lead concentrations and dust-lead levels, the linearized slope coefficients as described by Rust and Burgoon, and the slope coefficients reported by Marcus and Elias. Burgoon and Rust did not originally report results for the blood/dust coefficients, so such results were prepared for this paper. The Rochester Lead-in-Dust Study and Baltimore Repair and Maintenance Study calculations as well as calculations for the studies previously considered by Rust and Burgoon are incorporated into this table. As in Table 1, for each identified study, the Rust and Burgoon results include the estimated linearized slope coefficient for a range of dust-lead levels (100 to 800 ppm or 100 to 800 µg/ft^2). In addition, the slope estimate and associated dust-lead level is reported for a range of potential blood-lead concentrations (2.5-30 µg/dL). Again, estimates outside the range of the observed data are indicated by an asterisk. The relevant results from Marcus and Elias are reported in the last two columns.

Table 3 presents the specific regression equations from which the linearized slope coefficients in Tables 1 and 2 were calculated. It also presents the specific equations fitted by Marcus and Elias.

If the differences in the underlying fitted regression models are ignored and the coefficient estimates considered together, among urban communities the reported soil slope coefficients (µg/dL per 1000 ppm at the geometric mean soil-lead concentration) range between 0.15 and 14.38, while among smelter communities the range is between 0.03 and 11.91. The dust slope concentration coefficients (µg/dL per 1000 ppm) range from 0.01 to 10.44 among urban communities (at the geometric mean dust-lead concentration) and from 1.36 to 10.60 among smelter communities.

In her report, Dr. Mahaffey concluded that the estimated slope coefficients were highly variable and that, "there is little indication of common environmental factors that can explain these differences." In the case of coefficients estimated from the published results, the varied fitted regression equations presented in Table 3 explain some of these differences. The additional variables (e.g., age, XRFhazard) fitted as part of the reported regression results affect, potentially significantly, the estimated coefficients on dust or soil lead. Marcus and Elias, similarly, suggest many reasons for the large range of slope coefficient estimates relative to the small uncertainties associated with some of them —

> *"Site specific factors include soil-to-dust and paint-to-dust transfer rates, lead particle bioavailability, and bioaccessibility. Population specific factors include soil and dust ingestion rates, hand-to-mouth transfer, child nutrition, and parental awareness of lead hazards. Slope factors may be highly sensitive to recruitment biases and measurement errors in the data base."*

Mahaffey suggests additional possible reasons for these differences,

- *"Recognition that the contemporaneous environmental lead is only one source of lead to blood. Remobilization of lead from body stores to blood constitutes an "internal" source of lead. Quantitatively the comparative importance of these external and internal sources will vary.*

- *Differences in the response of blood lead to soil and/or dust lead concentrations depend on the concentration range being evaluated.*

- *Relative importance for the children of soil or dust lead compared with lead from other sources.*

- *Personal characteristics of the children, such as their ages, which will greatly modify their ingestion of lead, the fractional absorption of ingested lead, and age-dependent differences in lead biokinetics which establish the association between blood lead and environmental lead dose.*

- *Recognition that a number of other factors contribute to the range of differences in the slope factors identified in these studies: hygiene within the home, ethnic/racial characteristics of the subjects, nutritional status of the subjects, and other factors (e.g. community awareness of lead as a health hazard)."*

On top of these factors are differences in sampling methods employed, the locations sampled, and the timing (season) of the sampling.

The results from the studies considered are qualitatively similar in that the association between environmental lead and blood lead is consistently positive and, when considered without the confounding from additional variables, statistically significant. However, it is very problematic to combine these disparate results into a single set of coefficients that provide one representative quantitative measure of the relationship between blood-lead level concentration and soil- or dust-lead level.

4.0 References

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[2] Centers for Disease Control and Prevention, "Preventing Lead Poisoning in Young Children—A Statement by the Centers for Disease Control." Public Health Service, U. S. Department of Health and Human Services, October 1991.

[3] Mahaffey, Kathryn R., (1994) "Analysis of Epidemiological Data on Association between Blood Lead and Lead in Soil and Dust for OPPTS/EPA," U.S. Environmental Protection Agency.

[4] The University of Rochester School of Medicine and The National Center for Lead-Safe Housing, (1995) "The Relation of Lead-Contaminated House Dust and Blood Lead Levels Among Urban Children," Departments of Pediatrics, Biostatistics, and Environmental Medicine, Final Report, Volume 2, June 1995.

[5] Strauss, Warren J. and Steven W. Rust, (1995) "Statistical Evaluation of the Relationship Between Blood-Lead and Dust-Lead Based on Pre-intervention Data from the R&M Study," Battelle deliverable to U.S. Environmental Protection Agency on Task 3-13 Contract 68-D2-0139, September 1995.

[6] Eberly, Shirly. (1995). Department of Biostatistics, University of Rochester School of Medicine and Dentistry, Rochester, New York, Personal Communication October 1995.

[7] Rust, Steven W. and David A. Burgoon, (1993) "Development of Health-Based Standards for Lead in Residential Environments," Battelle deliverable to U.S. Environmental Protection Agency on Task 2-8 Contract No. 68-D2-0139, December 1993.

[8] Marcus, Allan H. and R. W. Elias, (1994) "Estimates of Soil and Dust Lead Slope Factors for U.S. Children, ages 12 to 84 Months, Based on Consistent Analyses of Studies Since 1980." Environmental Criteria and Assessment Office. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina, January 1994.

Table 1. Derived Slope Estimates for the Sixteen Identified Studies of Lead Exposure From Soil Lead.

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbS Range (ppm)	Slope Determined for	PbB (µg/dL)	PbS (ppm)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Urban Communities								
Boston Women's Hospital (1980-1983)	nr	nr	Geometric Mean PbS	nc	365.00	2.19	0.34 @ 12 mos. 1.09 @ 18 mos. 2.30 @ 24 mos.	nc
Cincinnati Longitudinal Lead Study (1980-1987)	6.0-53.5	76-54519	Geometric Mean PbS Soil at 500 ppm Soil at 1000 ppm Soil at 1500 ppm Soil at 2000 ppm Blood at 10 µg/dL Blood at 15 µg/dL Blood at 20 µg/dL	16.13 15.08 15.80 16.23 16.55 10.00 15.00 20.00	1360.32 500.00 1000.00 1500.00 2000.00 1.08 452.62 33391.61	0.79 2.02 1.06 0.72 0.55 621.47* 2.20 0.04	nr	nr
New Haven, Connecticut Lead Study (1977)	nr	30-7000	Geometric Mean PbS Soil at 500 ppm Soil at 1000 ppm Soil at 1500 ppm Soil at 2000 ppm Blood at 25 µg/dL Blood at 30 µg/dL	29.97 29.08 30.31 31.05 31.59 25.00 30.00	826.30 500.00 1000.00 1500.00 2000.00 39.23 834.58	2.16 3.47 1.81 1.23 0.94 37.98 2.14	nr	nr

Table 1. (Continued).

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbS Range (ppm)	Slope Determined for	PbB (µg/dL)	PbS (ppm)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Urban Communities (continued)								
Omaha Lead Study (1970-1977)	nr	16-4792	Geometric Mean PbS Soil at 500 ppm Soil at 1000 ppm Soil at 1500 ppm Soil at 2000 ppm Blood at 20 µg/dL Blood at 25 µg/dL Blood at 30 µg/dL	21.55 24.29 26.98 28.69 29.97 20.00 25.00 30.00	227.00 500.00 1000.00 1500.00 2000.00 138.70 605.07 2015.96	14.38 7.36 4.09 2.90 2.27 21.84 6.26 2.25	nr	nr
Baltimore USLADP Area 1 (1989)	3.2-40.2	212.2-1094.9	Geometric Mean PbS	nr	459.0	nr	0.58	3.38
Baltimore USLADP Area 2 (1989)	5.4-28.9	145.6-893.0	Geometric Mean PbS	nr	295.6	nr	0.81	0
Boston USLADP (1989)	7-22	820.8-5000	Geometric Mean PbS	nr	nr	nr	0.24	0.15
Cincinnati USLADP (1989)	2-33.5	nr	Geometric Mean PBS	nr	nr	nr	3.57	nr
#Rochester Lead-In-Dust Study (1994)	1.4-31.7	15-35000	Geometric Mean PbS Soil at 500 ppm Soil at 1000 ppm Soil at 1500 ppm Soil at 2000 ppm Blood at 5 µg/dL Blood at 10 µg/dL	6.38 5.73 6.40 6.82 7.14 5.00 10.00	981.00 500.00 1000.00 1500.00 2000.00 212.21 16593.92	1.03 1.82 1.02 0.72 0.57 3.74 0.10	nr	nr

Table 1. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbS Range (ppm)	Slope Determined for	PbB (µg/dL)	PbS (ppm)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Smelter Communities								
Butte-Silver Bow Environmental Health Lead Study (1990)	1.0-25.0	72-2356	Geometric Mean PbS	7.43	516.00	3.72	2.0	0
			Soil at 500 ppm	7.87	500.00	3.81		
			Soil at 1000 ppm	9.31	1000.00	2.25		
			Soil at 1500 ppm	10.27	1500.00	1.66		
			Soil at 2000 ppm	11.01	2000.00	1.33		
			Blood at 5 µg/dL	5.00	76.75	15.76		
			Blood at 10 µg/dL	10.00	1345.70	1.80		
Kellogg Revisited Lead Study (1983)	1-45	37-41200	Geometric Mean PbS	14.65	1548.00	0.58	0.15	0.03
			Soil at 500 ppm	13.66	500.00	1.68		
			Soil at 1000 ppm	14.26	1000.00	0.88		
			Soil at 1500 ppm	14.62	1500.00	0.60		
			Soil at 2000 ppm	14.88	2000.00	0.46		
			Blood at 10 µg/dL	10.00	3.13	196.74*		
			Blood at 15 µg/dL	15.00	2256.77	0.41		
			Blood at 20 µg/dL	20.00	240570.40	0.01*		
Leadville Metals Exposure Study (1988)	0.5-30.1	10-27800	Geometric Mean PbS	2.31	914.70	0.61	nr	nr
			Soil at 500 ppm	1.99	500.00	0.96		
			Soil at 1000 ppm	2.36	1000.00	0.57		
			Soil at 1500 ppm	2.61	1500.00	0.42		
			Soil at 2000 ppm	2.81	2000.00	0.34		
			Blood at 2.5 µg/dL	2.50	1255.86	0.48		
			Blood at 5 µg/dL	5.00	20093.75	0.06		

Table 1. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbS Range (ppm)	Slope Determined for	PbB (µg/dL)	PbS (ppm)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Smelter Communities (continued)								
Midvale Community Lead Study (1989)	0.5-22.5	58-6665	Geometric Mean PbS	4.13	398.91	1.18	1.52	2.16
			Soil at 500 ppm	4.24	500.00	0.97		
			Soil at 1000 ppm	4.59	1000.00	0.52		
			Soil at 1500 ppm	4.81	1500.00	0.37		
			Soil at 2000 ppm	4.97	2000.00	0.28		
			Blood at 2.5 µg/dL	2.50	4.83	59.01*		
			Blood at 5 µg/dL	5.00	2109.65	0.27		
Telluride Lead Study (1986)	<2-19	17-804	Geometric Mean PbS	6.90	178.00	6.78	nr	nr
			Soil at 500 ppm	8.27	500.00	2.89		
			Soil at 1000 ppm	9.33	1000.00	1.63		
			Soil at 1500 ppm	10.02	1500.00	1.17		
			Soil at 2000 ppm	10.53	2000.00	0.92		
			Blood at 5 µg/dL	5.00	28.15	31.05		
			Blood at 10 µg/dL	10.00	1484.95	1.18		
			Blood at 15 µg/dL	15.00	15105.29	0.17*		
Helena Valley — PbA < 0.5 (1983)	nr	nr	Geometric Mean PbS	nr	nr	nr	6.41	0

Table 1. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbS Range (ppm)	Slope Determined for	PbB (µg/dL)	PbS (ppm)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Smelter Communities (continued)								
Smelterville (1983)	nr	nr	Geometric Mean PbS	nr	nr	nr	1.15	0.12
Pinehurst (1983)	nr	nr	Geometric Mean PbS	nr	nr	nr	11.91	3.30

‡ For many studies these results were originally reported in Rust and Burgoon (1994). Ranges reported for three USLADP were reproduced from Marcus and Elias (1994).

‡‡ For many studies these results were originally reported in Rust and Burgoon (1994). The results for the Rochester Lead-in-Dust Study are new. The results for the Butte-Silver Bow Environmental Health Study have been corrected.

† Slope coefficient reported in Marcus and Elias (1994) based on fitted nonlinear regression equation of PbS and PbD simultaneously predicting PbB.

§ Slope coefficient based on published regression equations in Table 3.

Rochester Lead-in-Dust Study results reported were based on personal communication [6].

nr Not reported.

nc Not calculable (e.g., the intercept in the regression was not reported).

c Constrained to zero as part of the regression coefficient estimation procedure.

* Estimates are unrealistic as a result of extrapolating beyond the limits of the data. Soil concentration is outside the range of the data.

Table 2. Derived Slope Estimates for the Fifteen Identified Studies of Lead Exposure From Dust Lead

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Urban Communities								
Boston Women's Hospital (1980-1983)	nr	nr	Geometric Mean PbD	nc	nc	nc	0.02 @ 12 mos. 0.49 @ 18 mos. 0.32 @ 24 mos.	nc
Cincinnati Longitudinal Lead Study (1980-1987)	6.0-53.5	82-13820	Geometric Mean PbD	16.94	899.85	4.65	nr	nr
			Dust at 100 ppm	9.78	100	24.24		
			Dust at 200 ppm	11.63	200	14.40		
			Dust at 400 ppm	13.83	400	8.56		
			Dust at 800 ppm	16.45	800	5.08		
			Blood at 10 µg/dL	10.00	111.02	22.41		
			Blood at 20 µg/dL	20.00	1796.06	2.77		
			Blood at 25 µg/dL	25.00	4400.59	1.41		
			Blood at 30 µg/dL	30.00	9151.72	0.82		

Table 2. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm) §	Children 12-35 months of age	Children 36-84 months of age
Urban Communities								
Omaha Lead Study (1970-1977)	nr	18-5571	Geometric Mean PbD	21.39	337	10.44	nr	nr
			Dust at 100 ppm	17.52	100	28.82		
			Dust at 200 ppm	19.63	200	16.15		
			Dust at 400 ppm	22.01	400	9.05		
			Dust at 800 ppm	24.66	800	5.07		
			Blood at 10 µg/dL	10	3.31	497.11*		
			Blood at 15 µg/dL	15	38.92	63.40		
			Blood at 20 µg/dL	20	223.72	14.71		
			Blood at 25 µg/dL	25	868.62	4.73		
			Blood at 30 µg/dL	30	2631.31	1.88		
Baltimore USLADP Area 1 (1989)	3.2-40.2	226.3-10577.8	Geometric Mean PbD	nr	2221.6	nr	0.14	0.40
Baltimore USLADP Area 2 (1989)	5.4-28.9	425.0-16503.8	Geometric Mean PbD	nr	2235.0	nr	0.01	0.05
Boston USLADP (1989)	7-22	150-107201	Geometric Mean PbD	nr	nr	nr	0.08	0.06
Cincinnati USLADP (1989)	2-33.5	30-3696	Geometric Mean PbD	nr	nr	nr	2.93	nr

Table 2. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Urban Communities (continued)								
Baltimore Repair & Maintenance (on-going)	0.90-65.5	48.9-60304.2	Geometric Mean PbD	nr	nr	nr	nr	nr
			Dust at 100 ppm	3.73	100	11.76		
			Dust at 200 ppm	4.64	200	7.31		
			Dust at 400 ppm	5.77	400	4.55		
			Dust at 800 ppm	7.18	800	2.83		
			Blood at 5 µg/dL	5	253.31	6.22		
			Blood at 10 µg/dL	10	2287.86	1.38		
			Blood at 15 µg/dL	15	8289.33	0.57		
			Blood at 20 µg/dL	20	20663.32	0.31		
			Blood at 25 µg/dL	25	41965.21	0.19		
			Blood at 30 µg/dL	30	74866.90	0.12		
#Rochester Lead-In-Dust Study (1994)	1.4-31.7	30.7-17877.9	Geometric Mean PbD	5.51	528	1.38	nr	nr
			Dust at 100 ppm	4.43	100	5.84		
			Dust at 200 ppm	4.85	200	3.20		
			Dust at 400 ppm	5.31	400	1.75		
			Dust at 800 ppm	5.82	800	0.96		
			Blood at 2.5 µg/dL	2.5	19.80	17.46*		
			Blood at 5 µg/dL	5	30056.33	2.30		

Table 2. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Urban Communities (continued)								
#Rochester Lead-In-Dust Study (1994)	1.4-31.7	4.3-12136.6				Based on dust loading (µg/dL per 1000 µg/ft^2)	nr	nr
			Geometric Mean PbD	3.46	11	56.87		
			Dust at 100 µg/ft^2	5.15	100	9.33		
			Dust at 200 µg/ft^2	5.84	200	5.29		
			Dust at 400 µg/ft^2	6.62	400	3.00		
			Dust at 800 µg/ft^2	7.51	800	1.70		
			Blood at 5 µg/dL^2	5	84.68	10.69		
			Blood at 10 µg/dL^2	10	3899.00	0.46		
Smelter Communities								
Butte-Silver Bow Environmental Health Lead Study (1990)	1.0 -25.0	189 - 1697					1.83	1.78
			Geometric Mean PbD	7.85	484.00	8.08		
			Dust at 100 ppm	3.58	100.00	17.83*		
			Dust at 200 ppm	5.06	200.00	12.59		
			Dust at 400 ppm	7.14	400.00	8.89		
			Dust at 800 ppm	10.08	800.00	6.28		
			Blood at 2.5 µg/dL	2.50	48.63	25.60*		
			Blood at 5 µg/dL	5.00	195.60	12.73		
			Blood at 10 µg/dL	10.00	786.76	6.33		
			Blood at 20 µg/dL	20.00	3164.54	3.15*		

Table 2. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Smelter Communities								
Kellogg Revisited Lead Study (1983)	1-45	221-10395	Geometric Mean PbD	14.64	2073	1.77	3.13	1.72
			Dust at 100 ppm	6.86	100	17.17*		
			Dust at 200 ppm	8.16	200	10.21*		
			Dust at 400 ppm	9.70	400	6.07		
			Dust at 800 ppm	11.54	800	3.61		
			Blood at 5 µg/dL	5	28.13	44.42*		
			Blood at 10 µg/dL	10	450.09	5.55		
			Blood at 20 µg/dL	15	2278.13	1.65		
			Blood at 25 µg/dL	20	7200.00	0.69		
			Blood at 30 µg/dL	25	17578.13	0.36*		
Midvale Community Lead Study (1989)	0.5-22.5	119-3602	Geometric Mean PbD	nr	438	nr	0	0[c]
Telluride Lead Study (1986)	<2-19	86-3165	Geometric Mean PbD	6.85	281	10.60	nr	nr
			Dust at 100 ppm	4.36	100	18.99		
			Dust at 200 ppm	5.90	200	12.85		
			Dust at 400 ppm	7.99	400	8.69		
			Dust at 800 ppm	10.81	800	5.88		
			Blood at 2.5 µg/dL	2.5	27.91*	39.01*		
			Blood at 5 µg/dL	5	136.87	15.91		
			Blood at 10 µg/dL	10	671.25	6.49		
			Blood at 15 µg/dL	15	1701.51	3.84		
			Blood at 20 µg/dL	20	3291.88*	2.65*		

Table 2. (Continued)

Study	Data ranges ‡		Linearized slope coefficients as described in Rust and Burgoon (1993) ‡‡				Slope (µg/dL per 1000 ppm) reproduced from Marcus and Elias (1994)†	
	PbB Range (µg/dL)	PbD Range (ppm)	Slope Determined for	PbB (µg/dL)	PbD (ppm or µg/ft^2)	Slope (µg/dL per 1000 ppm)§	Children 12-35 months of age	Children 36-84 months of age
Smelter Communities (continued)								
Helena Valley — PbA < 0.5 (1983)	nr	nr	Geometric Mean PbD	nr	nr	nr	3.01	0
Smelterville (1983)	nr	nr	Geometric Mean PbD	nr	nr	nr	0	0[c]
Pinehurst (1983)	nr	nr	Geometric Mean PbD	nr	nr	nr	1.36	3.65

‡ For many studies these results were reported in Rust and Burgoon (1994). Ranges reported for three USLADP were reproduced from Marcus and Elias (1994).

‡‡ For many studies these results were originally reported by Rust and Burgoon (1994). The results for Rochester Lead-in-Dust and Baltimore Repair and Maintenance Studies are new. The results for Cincinnati Longitudinal Lead Study and Telluride Leadfs Study have been corrected.

† Slope coefficient reported in Marcus and Elias (1994) based on fitted nonlinear regression equation of PbS and PbD simultaneously predicting PbB.

§ Slope coefficients based on published regression equations in Table 3.

Rochester Lead-in-Dust Study results were based upon personal communication [6].

nr Not reported.

nc Not calculable (e.g., the intercept in the regression was not reported).

c Constrained to zero as part of the regression coefficient estimation procedure.

* Estimates are unrealistic as a result of extrapolating beyond the limits of the data. Dust level is outside the range of the data.

Table 3. Reported Regression Results for Seventeen Identified Lead Exposure Studies

Study	Reported Regression Results	r	Values of Additional Variables
Urban Communities			
Boston Women's Hospital (1980-1983)	$PbB = 2.2 + 1.7 \cdot PbD^{(1)} + 2.1 \cdot Season + 1.2 \cdot Refinish + 0.8 \cdot lnPbS$	0.32	N/A
(Ages: 12 months)	$lnPbB = ln\ (5.47 + 0.34 \cdot PbS + 0.02 \cdot PbD)$	N/A	N/A
(Ages: 18 months)	$lnPbB = ln\ (3.85 + 1.09 \cdot PbS + 0.49 \cdot PbD)$	N/A	N/A
(Ages: 24 months)	$lnPbB = ln\ (2.73 + 2.30 \cdot PbS + 0.32 \cdot PbD)$	N/A	N/A
Cincinnati Longitudinal (1980-1987)	$lnPbB = 1.276 + 0.152 \cdot lnPbH + 0.182 \cdot lnPbD^{(3)}$	0.38	N/A
	$lnPbH = -0.966 + 0.444 \cdot lnPbD^{(3)}$	0.22	N/A
	$lnPbD = 4.691 + 0.325 \cdot ln(XRFHazard) + 0.268 \cdot lnPbS$	0.52	XRFHazard = 1
New Haven, Connecticut (1977)	$logPbB = 1.30267 + 0.05963 \cdot logPbS$	0.22	N/A
Omaha Lead Study (1970-1977)	$logPbB = 0.9766 + 0.1515 \cdot logPbS$	0.38	N/A
	$logPbB = 0.9145 + 0.1645 \cdot logPbD^{(5)}$	0.29	N/A
#Rochester Lead-in-Dust Study (1994)	$logPbB = 0.801 + 0.159 \cdot logPbS - 0.472 \cdot I_{Soil}$	0.13	$I_{Soil} = 1$
	$logPbB = 0.382 + 0.132 \cdot logPbD^{(6)}$	0.07	N/A
	$logPbB = 0.350 + 0.181 \cdot logPbD^{(7)}$	0.21	N/A
◇Repair & Maintenance Study (on-going)	$logPbB = -0.119 + 0.315 \cdot logPbD^{(7)} + log(1.22)/2 \cdot cos\ [2\pi\ (day - 7/24/93)/365]$	N/A	day = 11/1/93
Baltimore USLADP Area 1 (1989)			
(Ages: 12-35 months)	$lnPbB = ln\ (9.54 + 0.00058 \cdot PbS + 0.00014 \cdot PbD)$	N/A	N/A
(Ages: 36-84 months)	$lnPbB = ln\ (6.86 + 0.00383 \cdot PbS + 0.00040 \cdot PbD)$	N/A	N/A

Table 3. (Continued)

Study	Reported Regression Results	r	Values of Additional Variables
Urban Communities (Continued)			
Baltimore USLADP Area 2 (1989)			
(Ages: 12-35 months)	lnPbB = ln (10.45 + 0.00081 · PbS + 0.00001 · PbD)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln (8.44 + 0 · PbS + 0.00005 · PbD)	N/A	N/A
Boston USLADP (1989)			
(Ages: 12-35 months)	lnPbB = ln (11.14 + 0.00024 · PbS + 0.00008 · PbD)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln (10.75 + 0.00015 · PbS + 0.00006 · PbD)	N/A	N/A
Cincinnati USLADP (1989)			
(Ages: 12-35 months)	lnpbB = ln (8.05 + 0.00357 PbS + 0.00293 PbD)	N/A	N/A
Smelter Communities			
Butte-Silver Bow Environmental Health Lead Study (1990)	lnPbB = -2.170 + 0.048 · Age + 0.498 · $\ln PbD^{(2)}$ + 0.074 · Mouths + 0.058 · Work	0.20	Age = 24 months, Work = 0 (Parents work), Mouths = 0 (Mouthing Behavior)
	lnPbD = 3.167 + 0.485 · lnPbS	0.46	N/A
Kellogg Revisited Lead Study (1983)	lnPbB = 0.1559 + 0.0616 · lnPbS + 0.2500 · $\ln PbD^{(4)}$ + 0.1139 · Age - 0.0152 · Age^2 + 0.2045 · SmokeT - 0.1401 · VitaminT	0.33	SmokeT=0, VitaminT = 0, Age = 2 years, Geometric Mean PbD = 2073
Leadville Metals (1988)	PbB = 0.42 · $PbS^{0.25}$		N/A
Midvale Community (1989)	lnPbB = 1.159 + 0.164 · lnXRF + 0.114 · lnPbS - 0.016 · SES + 0.090 · Mouths	0.28	Mouths = 0, XRF = 1, Geometric Mean SES = 26.4
(Ages: 12-35 months)	lnPbB = ln(4.62 + 0.00152 PbS)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln(4.14 + 0.00216 PbS)	N/A	N/A

Table 3. (Continued)

Study	Reported Regression Results	r	Values of Additional Variables
Smelter Communities (Continued)			
Telluride Lead Study (1986)	lnPbB = -0.545 + 0.494 · lnPbH + 0.128 · Age - 60.140 · (lnPbHxAge) + 0.347 · lnPbD[(6)]	0.44	Age = 2 years
	lnPbH = -1.582 + 0.218 · Age + 0.420 · lnPbD[(6)]	0.32	Age = 2 years
	lnPbD = 3.573 + 0.400 · lnPbS	0.45	Age = 2 years
Helena Valley — PbA < 0.5 (1983)			
(Ages: 12-35 months)	lnPbB = ln (5.27 + 0.00641 · PbS + 0.00301 · PbD)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln (7.44 + 0 · PbS + 0 · PbD)	N/A	N/A
Smelterville (1983)			
(Ages: 12-35 months)	lnPbB = ln (10.95 + 0.00115 · PbS + 0 · PbD)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln (23.48 + 0.00012 · PbS + 0 · PbD)	N/A	N/A
Pinehurst (1983)			
(Ages: 12-35 months)	lnPbB = ln (4.25 + 0.01191 · PbS + 0.00136 · PbD)	N/A	N/A
(Ages: 36-84 months)	lnPbB = ln (5.50 + 0.00330 · PbS + 0.00365 · PbD)	N/A	N/A

PbB Blood-lead concentration
PbD Lead in dust
PbS Lead in soil
PbH Lead on hands
ln natural logarithm
log Base 10 logarithm
◦ This paper has not been peer reviewed and the authors of this paper state that the selected model was chosen because of its simplicity, and is noted as being rather approximate.
Rochester Lead-In-Dust Study results were based upon personal communication [6]
(1) Wet wipe sample, the units of the dust measurement were unclear in the published literature
(2) Vacuum sample, concentration
(3) Vacuum sample, concentration
(4) Vacuum sample + household vacuum cleaner bag, concentration
(5) Household vacuum cleaner bag or sweeping if no vacuum cleaner available, concentration
(6) Vacuum sample, concentration
(7) Vacuum sample, loading
(8) Weighted arithmetic average for 3 age groups
(9) Vacuum sample, concentration