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Exposure Assessment Articles

Evaluation of the Contribution of Lead in Soil to Lead in Dust at Superfund Sites

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ABSTRACT

The concentration of lead in indoor dust is a key parameter in the Integrated Exposure Uptake Biokinetic (IEUBK) model used by the U.S. Environmental Protection Agency (USEPA) to evaluate risks to children from lead in soil. The default assumption is that the concentration of lead in indoor dust is 70% of the concentration of lead in outdoor soil. This report reviews the basis of this assumption, and compares the assumption to data obtained at mining/smelting Superfund sites in USEPA Region 8. Data for lead concentrations measured in both indoor dust and outdoor soil at a number of different properties at nine different Superfund sites were fit to a linear model (Cdust = K0 + Ksd·Csoil). Based on ordinary linear regression, values of Ksd ranged from 0.04 to 0.34. Values of Ksd estimated using a simple method to account for measurement errors yielded values from 0.04 to 0.35. These findings indicate that the concentration of lead in dust at mining/smelting sites in Region 8 is usually not as large as the IEUBK default assumption indicates. Use of the default is likely to be protective, but will likely result in an overestimation of childhood exposure and risk from lead in soil.

Key Words: lead, soil, dust, IEUBK.

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DISCLAIMER: SRC, Inc. is a contractor for USEPA. The authors declare there are no specific potential competing financial interests as a consequence of employment. The opinions expressed in this report are not necessarily those of the U.S. Environmental Protection Agency.
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INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) has developed an Integrated Exposure, Uptake and Biokinetic (IEUBK) model (USEPA 1994) for evaluating risks to children from exposures to lead in environmental media, including outdoor soil, indoor dust, air, water, and food. Of these exposure media, exposures from soil and dust are often the largest contributors. The concentration of lead in outdoor soil is typically measured at every exposure unit (usually a residential property) that is evaluated. This may be achieved either by collecting a series of grab samples and finding the average concentration, or by collecting one or more composite samples that represent the exposure unit.

Conceptually, the concentration of lead in indoor dust could also be measured at every exposure unit, by collecting one or more indoor dust samples (usually using a microvacuum technique), and averaging the results. However, this is rarely done because of cost as well as the disruption to residents inside their homes. Rather, the concentration of lead in indoor dust is usually calculated from the measured concentration of lead in outdoor soil using an equation of the following form (USEPA 1998):

$$\text{Cdust} = \text{K0} + \text{Ksd} \cdot \text{Csoil}$$

where: Cdust = average concentration of lead in indoor dust (mg Pb/kg dust); K0 = average concentration of lead in indoor dust (mg Pb/kg dust) that is not attributable to soil; and Ksd = average mass fraction of soil in dust (kg soil per kg dust). Because Ksd is a mass fraction, it is bounded between 0 and 1; Csoil = average concentration of lead in outdoor yard soil (mg Pb/kg soil).

This model is based on the concept that the concentration of lead in indoor dust is the mass-weighted average of several source terms:

$$\text{Cdust} = \sum [\text{C(i)} \cdot \text{MF(i)}]$$

where: C(i) = Concentration of lead in source material "i" that contributes to indoor dust; MF(i) = Mass fraction of source material "i" in indoor dust.

Because both the lead concentrations and the mass fractions of different source materials (*e.g.*, soil, paint, dust from ambient air) may vary widely from property to property and from site to site, it is expected that there may be substantial variability in the relationship between soil and dust, both within a site and between sites. At many sites, the mean concentration of lead in indoor dust is higher than in outdoor soil (Paustenbach *et al.* 1997). However, when soil lead levels are high (*e.g.*, at mining/smelting sites), the concentration of lead in indoor dust may tend to be lower than outdoor soil (Paustenbach *et al.* 1997; Oomen and Lijzen 2004). The purpose of fitting a site-specific dataset to a linear model is to estimate the site-specific average contribution of soil lead to dust lead.

The basic data needed to estimate K0 and Ksd at a site consist of paired datasets where the concentration of lead in outdoor soil and indoor house dust are both measured at multiple exposure units (properties) at a site. The most common way to derive the parameter estimates is through ordinary linear regression (USEPA 1998). However, this approach may tend to underestimate the true slope and overestimate the intercept when there is significant measurement error due to sampling variability

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Table 1. Ksd values used to establish the IEUBK default value.

Site name	State	Contamination source	Measured Ksd
East Helena	Montana	Smelting	0.85
Midvale	Utah	Smelting	0.70
Butte	Montana	Mining, milling and smelting	0.26
Kellogg	Idaho	Smelting	0.09

Source: USEPA (1994).

in the collection of the soil values. As noted earlier, because both indoor dust and outdoor soil concentrations are estimated using the mean of several grab or composite samples from a property, measurement error is likely to be present in both values, with the magnitude of the error depending on the sampling design and the magnitude of the between-sample variability.

When measurement error is present in both the dependent and the independent variables, more advanced methods such as minimization of the chi-square merit function (Press *et al.* 1992), the geometric mean functional relationship (Draper and Smith 1998), or structural equation modeling (USEPA 1994) may be appropriate to help minimize the effect of measurement error. However, such complex analyses may not always be warranted or possible, due to limitations in the available data. An alternative and relatively simple approach first proposed by Bartlett (1949) is described by Draper and Smith (1998). In this approach, the data are divided into three groups of approximately equal size based on the values of soil lead, and the mean concentration of lead in soil and dust are computed for each group. The regression line is established by requiring the line to pass through the overall center of gravity $(\overline{X}, \overline{Y})$ with slope (Ksd) and intercept (K0):

$$Ksd = \frac{\overline{PbD}_3 - \overline{PbD}_1}{\overline{PbS}_3 - \overline{PbS}_1}$$

$$K0 = \overline{PbD} - Ksd \cdot \overline{PbS}$$

The USEPA has established a default value of 0.7 for the Ksd parameter (USEPA 1994). This value is stated to be appropriate for neighborhoods or residences in which loose particles of surface soil are readily transported into the house, where soil is a major contributor to household dust, and where leaded paint does not contribute greatly to indoor dust (USEPA 1994).

The default value was selected by USEPA after a review of data from four Superfund sites,[1] as shown in Table 1. As seen, all four of the sites are mining/smelting sites. Based on these data, USEPA (1994) selected a default value of 0.7 to be near the upper end of the range of measured Ksd values at these sites. No information is provided in USEPA (1994) on the sizes of the paired soil–dust datasets available at these sites, or on the statistical method(s) used to estimate the values of Ksd.

[1]Editor's note: Superfund sites are uncontrolled hazardous waste sites that fall under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended.

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This report summarizes information on the range of Ksd values that have been measured for a number of other mining and smelting Superfund sites in USEPA Region 8 (encompassing much of the Rocky Mountain section of the western United States), and compares these data to the default value recommended for use in the IEUBK model. The purpose is to evaluate whether the default value is reasonable or may be unduly conservative for use at sites of this type.

DATA

Several examples of site-specific data on the relationship between lead levels in outdoor yard soil and indoor dust are presented in Figure 1. As seen, in all three examples, there is a trend for the concentration of lead in indoor dust to increase as a function of increasing lead in outdoor soil, but the observed magnitude of the increase is not as large as the default assumption.

Summarized in Table 2 are the data from these examples as well as a number of other mining and smelting Superfund sites that have been studied in Region 8. As shown in Table 2, values of Ksd appear to vary substantially between sites. As noted earlier, this is not unexpected, because the value of Ksd is likely to depend on a number of site-specific variables that influence the rate and extent of soil transfer into homes, as well as the rate and extent that indoor dust is removed by cleaning.

When Ksd values are estimated by ordinary linear regression, the site-specific Ksd estimates at these sites range from 0.04 to 0.34 (average = 0.17). When the parameter estimates are based on Bartlett's method, the slope usually increases somewhat, although in one case the slope derived by this method actually becomes negative. This is because the mean dust concentration for the first third of the samples is higher than the mean for the last third. When this result is excluded, Ksd values estimated by Bartlett's method range from 0.04 to 0.35 (average = 0.21).

These results support the conclusion that the default value of 0.7 for Ksd may be overly conservative, at least for mining, milling, and smelting sites in Region 8. These differences between site-specific values and default assumptions used in IEUBK model calculations may lead to an overestimate of the level of exposure and health risk to children from lead in soil, at least for mining, milling, and smelting sites in Region 8.

USEPA (1994) noted that empiric Ksd values may decrease over time at sites where major sources of lead deposition are no longer active. There are two examples from Region 8 (Midvale, Utah, and East Helena, Montana) that provide information on this issue. At these two sites, Ksd values were measured early in the site history and then again after substantial cleanup work had occurred. The data are shown in Table 3. As seen, initial measures of Ksd at these two sites were substantially higher than subsequent measures. This suggests that site cleanup may tend to diminish Ksd. If so, the mechanism is not certain. Recall that Ksd is a medium-specific transfer factor, describing the transfer of soil (not lead) from outdoors to indoors. As such, the value is expected to be independent of the concentration of lead in soil, so cleanup activities that have as their only effect a reduction in lead levels in the environment would not be expected to change Ksd.

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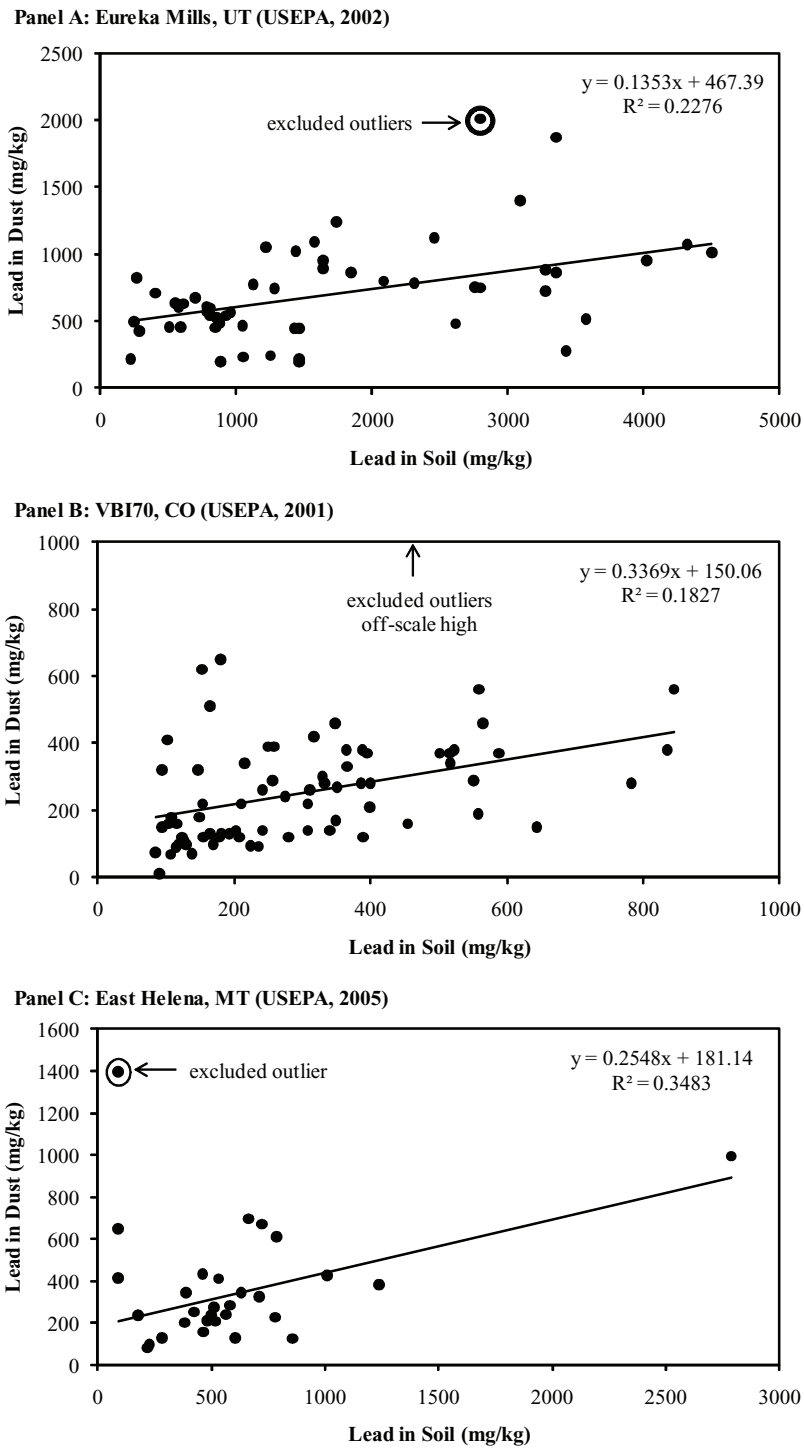

Figure 1. Example soil–dust datasets.

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Table 2. Soil–Dust relationships for lead at Region 8 mining/smelting Superfund sites.

Site	Location	Number of data pairs	Number of data pairs fitted[a]	Linear regression parameters			Bartlett's method		Source
				Slope (Ksd)	Intercept (K0)	R^2	Slope (Ksd)	Intercept (K0)	
Butte-Silverbow	Walkerville, MT	196	192	0.20 (0.13–0.26)[c]	280 (197–363)	0.14	0.27 (0.17–0.39)	206 (96–305)	UOS (2003)
California Gulch	Leadville, CO	200	196	0.14 (0.11–0.17)	565 (491–639)	0.35	0.23 (0.18–0.29)	434 (340–511)	USEPA (1996)
East Helena	East Helena, MT	30	29	0.25 (0.12–0.39)	181 (74–288)	0.35	0.27 (0.06–0.50)	173 (34–299)	USEPA (2005)
Eureka Mills	Eureka, UT	55	54	0.14 (0.07–0.20)	467 (329–606)	0.23	0.15 (0.07–0.23)	450 (316–578)	USEPA (2002)
Midvale Slag OU1	Midvale, UT	40	40	0.04 (-0.13–0.21)	289 (210–368)	0.01	-0.21 (-0.74–0.07)	384 (277–580)	ISSI (1998)
Midvale Slag OU2	Midvale, UT	90	88	0.09 (-0.01–0.20)	139 (123–156)	0.03	0.04 (-0.14–0.20)	146 (128–165)	Lanphear *et al.* (2003)
Murray Smelter	Murray, UT	22	21	0.19 (0.03–0.36)	174 (39–309)	0.24	0.23 (0.04–0.45)	150 (2–277)	USEPA (1997)
Sandy Smelter	Sandy, UT	165	161	0.12 (0.09–0.14)	122 (93–151)	0.37	0.15 (0.11–0.19)	98 (61–132)	USEPA (1995)
VBI70 OU1	Denver, CO	74	72[b]	0.34 (0.17–0.51)	150 (91–210)	0.18	0.35 (0.15–0.55)	146 (86–206)	USEPA (2001)

[a]Outliers characterized as values ±3 SD of the mean were excluded.
[b]Second outlier emerged after repeating the outlier analysis excluding the first outlier.
[c]Values in parentheses represent the 95% confidence intervals around the mean.

Table 3. Changes in soil–dust relationship for lead over time.

Site	Date	Ksd	K0	Source
East Helena	1983	0.70	—[a]	Kleinfelder (1995)
	2005	0.17	271	USEPA (2005)
Midvale Slag OU2	1989	0.66	208	Bornschein *et al.* (1991)
	1998	0.10	144	Lanphear *et al.* (2003)

[a]Value not reported.

However, site cleanup actions may do more than simply reduce lead concentrations. For example, excavation of soil followed by replacement with clean fill may tend to result in improved quality and extent of grass cover at a site. If so, this would be expected to result in a decrease in Ksd, since transfer of soil into indoor spaces is likely reduced by good vegetative cover. An alternative factor might be a change in population attributes as a function of time. For example, soil tracked into homes is suspected to be higher in homes that have children and/or pets than in homes with adults only and no pets. If the original data were collected at a time when the site was characterized by many families with young children and multiple pets, while the subsequent data were collected at a time when the number of children and pets had decreased, then the difference in these population parameters might account for a decreased soil to dust transfer.

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DISCUSSION

In general, default values selected for use in computing exposure and risk at Superfund sites are intended to be conservative. That is, default values are usually selected to be from the high end of their plausible range. However, in the case of the IEUBK model, the strategy used in developing the model was to calibrate the model so that realistic (rather than conservative) estimates of exposure were generated (Hogan *et al.* 1998; White *et al.* 1998). Consequently, IEUBK model default inputs are intended to be central tendency values, not high-end values.

With this in mind, it is apparent that the default value selected for Ksd is more nearly at the high-end than the central portion of the dataset considered in selecting the value (see earlier). In addition, Ksd values measured at a number of sites in USEPA Region 8 yield values mainly in the range of 0.1 to 0.4 (Table 2). Based on these considerations, it is concluded that the current default value for Ksd (0.7) is likely to be higher than actual for most mining, milling and smelting sites in Region 8, and that a somewhat lower default (*e.g.*, 0.4) is likely to provide more accurate estimates of lead exposure and risk in children.

In addition, available data suggest that Ksd may not be constant, but may change over time in response to changes in site conditions. These findings emphasize the value of collecting paired measurements of lead in soil and dust at Superfund sites in order to improve the accuracy of human health risk assessment for lead.

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