

## **A Parametric Distribution for the Fraction of Outdoor Soil in Indoor Dust**

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### **Abstract**

For a chemical which does not have a source inside a house, the ratio of its dust concentration indoors to its soil concentration outdoors is equal to the fraction of house dust which is composed of soil. To estimate the fraction of soil in house dust, we compiled ratios of the concentrations of a chemical in dust and soil from the scientific literature. We find that a LogNormal distribution fits the data extremely well. This distribution is suitable for use in public health risk assessments for single-family homes in temperate climates.

### **Introduction**

Ingestion of indoor dust is a significant exposure pathway for children in residential settings (Calabrese and Stanek, 1992, Dust; Stanek and Calabrese, 1992; Chuang et al., 1995; Fergusson and Kim, 1991). In one study, Stanek and Calabrese (1992) demonstrated that almost 50 percent of the soil ingested by children came from ingestion of soil in indoor dust. Measurements of contaminant concentrations in dust are difficult to perform and uncommon in human health risk assessment studies. Consequently, there is a need for a method to estimate the concentration of a chemical in dust from the concentration of that chemical in the soil outside the house.

The composition of indoor dust differs strongly from the composition of the soil outside a house. Only a fraction of dust is composed of soil which has been carried into the house (e.g., on shoes). The remainder consists of dust particles derived from material inside the house such as lint from carpets and clothes, human hair and skin, pet hair and skin, household plant material, pieces of paper, paint chips, wood chips from furniture, pieces of insulation, flakes of construction materials, bacteria, viruses, allergens and insects (e.g., dust mites) (Thatcher and Layton, 1995). Some indoor dust is also derived from particles carried through open windows by the wind.

Because indoor dust is a mixture of particles generated inside the house ("particles") and soil carried into the house on clothing, the concentration of a chemical in indoor dust must fall between its concentration in these two media. If the concentration of the chemical in the particles is negligible compared with its concentration in soil, the dust concentration of the chemical can be predicted from the physical dilution of the soil by particles. We define chemicals for which the particle concentration is negligible compared to the soil concentration as "conservative tracer chemicals".

Assuming that the soil carried into the house has the same chemical and physical properties as the outdoor soil, the ratio of the dust concentration to the soil concentration for conservative tracer chemicals is equal to the fraction of the household dust which consists of soil. For convenience, we define this ratio as the "transfer coefficient" (TC) of an chemical (Eqn 1).

$$TC = \frac{C_{dust}}{C_{soil}} \quad \text{Eqn 1}$$

where  $C_{dust}$  is the dust concentration of the element with units of mg/kg and  $C_{soil}$  is the soil concentration of the element with units of mg/kg. The TC is dimensionless. For conservative tracer chemicals, the maximum value for the TC, 1, represents dust

composed entirely of soil. The minimum value for the TC, 0, can only occur for dust which does not contain any soil. The TC for an element can only exceed a value of 1 if there are sources of that element from material inside the house.

We searched the scientific literature for studies in which the concentration of a chemical in both the dust and the soil was measured. To estimate the fraction of soil in house dust, we calculated the TC for all data pairs ( $C_{\text{dust}}$ ,  $C_{\text{soil}}$ ) which met the criteria for being conservative tracer chemicals as discussed below. We model the variability in the value of the TC by representing this ratio as a distribution.

#### Selection of Data for Conservative Tracers

We compiled data pairs ( $C_{\text{dust}}$ ,  $C_{\text{soil}}$ ) for rare earth elements (Binder et al., 1986; Bowen, 1979, Calabrese et al., 1989; Calabrese and Stanek, 1992, Dust; Calabrese and Stanek, 1992, Pica; Davis et al., 1990; Fergusson et al., 1986; Fergusson and Kim, 1991), heavy metals (Hartwell et al., 1983; Hawley, 1985; Liroy et al., 1992; Stern, 1994), several pesticides (Camann and Lewis, 1993; Simcox et al., 1995), and some organic compounds (Chuang et al., 1995). All the studies were conducted for single-family homes in temperate climates.

For each data pair, we determined whether it was a conservative tracer chemical based on three criteria. First, the data pair must be for one of the soil-derived elements proposed by Fergusson et al. (1986): hafnium (Hf), thorium (Th), scandium (Sc), samarium (Sm), cerium (Ce), lanthanum (La), manganese (Mn), sodium (Na), potassium (K), vanadium (V), aluminum (Al) and iron (Fe). Fergusson et al. (1986) showed that these elements do not have any sources or sinks within houses other than soil. Other chemicals, such as lead (Pb), arsenic (As), chromium (Cr), polycyclic aromatic hydrocarbons (PAHs), and some pesticides, can have higher dust concentrations than soil concentrations due to sources inside the house (e.g., lead

paint, tobacco smoke) (Hartwell et al., 1983; Liou et al., 1992; Chuang et al., 1995; Simcox et al., 1995). Therefore, these compounds are not expected to behave as conservative tracer chemicals. Second, the mean dust and soil concentrations for the element must be significantly different at the  $p < 0.05$  confidence level. Third, the dust concentration must be less than the soil concentration for the element. In theory, the TC can reach a maximum value of one for pure soil. In reality, it would be impossible for a conservative tracer chemical to have a TC value of one because of the large fraction of organic material which is always present in indoor dust (Rothenberg et al., 1989).

Table 1 shows the data pairs that meet these criteria and their associated TCs. Most of the values in Table 1 are mean values except those from Fergusson and Kim (1991) which are median values. We think the insights gained from including the median values outweigh the uncertainties introduced by their inclusion. It is not possible to test the second criteria for the data from Fergusson and Kim (1991) because only the median values for dust and soil concentrations are shown in this article. The values in Table 1 rely on studies with  $11 \leq N \leq 101$  data points.

#### Estimation of the Transfer Coefficient Distribution

By comparing the histogram of the TC values in Table 1 to Normal, Beta, and LogNormal distributions, we conclude that the LogNormal distribution represents the variability in the TC exceedingly well. In Figure 1,  $\ln[TC]$  has been plotted versus zscore. The solid line corresponds to a perfect LogNormal distribution while the points are the data from Table 1. All the points are clustered close to this line ( $r^2 = 0.9729$ ) which indicates that the data are well described by a LogNormal distribution. Ott (1995) notes that dilution processes tend to produce concentration distributions which are LogNormal in character. The fact that the values of TC are distributed LogNormally is consistent with Ott's observation because the variability in the TC results from the dilution of soil by particles.

We parameterize the LogNormal distribution as Eqn 2.

$$\underline{TC} \sim \exp[ \text{Normal}(\mu, \sigma) ] \quad \text{Eqn 2}$$

which is identical to

$$\ln[\underline{TC}] \sim \text{Normal}(\mu, \sigma) \quad \text{Eqn 3}$$

where  $\underline{TC}$  is a LogNormal random variable,  $\mu$  is the arithmetic mean of the Normal random variable  $\ln[\underline{TC}]$ , and  $\sigma$  is the arithmetic standard deviation of Normal random variable  $\ln[\underline{TC}]$ . By fitting a line to the points in Figure 1 using Mathematica™, we estimate that  $\hat{\mu} \pm se = -0.8767 \pm 0.0122$  and  $\hat{\sigma} \pm se = 0.3663 \pm 0.0125$ . Figure 2 shows the LogNormal probability density function (PDF) described by these parameters. This figure illustrates the properties of  $\underline{TC}$ . First, the minimum value for  $\underline{TC}$  is 0. Second, the mode of  $\underline{TC}$  is 0.3639. Third, the median of  $\underline{TC}$  is 0.4162. Fourth, the arithmetic mean and arithmetic standard deviation of  $\underline{TC}$  are 0.4450 and 0.1687, respectively. Figure 3 shows the cumulative distribution function (CDF) for this fitted distribution with the data from Table 1 superimposed on the graph. The PDF and CDF are alternative ways to represent the same information.

Even though a LogNormal distribution is defined from 0 to infinity, the probability of having a TC value greater than 1 is less than 1 percent given these fitted parameters. In practice, we recommend truncating the distribution of  $\underline{TC}$  at a maximum of 1 because TC values  $\geq 1$  are only possible for non-conservative tracer chemicals. Therefore, truncating the distribution at a maximum of 1 will change the distribution by only a negligible amount.

### Discussion

The fraction of soil in house dust is a random variable which closely follows a LogNormal distribution with an arithmetic mean of 0.445 and an arithmetic standard deviation of 0.1687. The arithmetic mean and arithmetic standard deviation  $\ln[TC]$  are -0.8767 and 0.3663, respectively. This parametric distribution is suitable for use in human health risk assessments for single family homes in temperate climates. These findings are consistent with the conclusions of Calabrese and Stanek (1992, Dust) that the mean fraction of indoor dust originally derived from soil is 0.313. Therefore, for a conservative tracer chemical, its concentration in house dust is expected to be less than half its concentration in the soil outside the home.

In this paper, we compare the bulk chemical compositions of soil and indoor dust because these were the only properties which were measured in the original studies. If the data were available, it would be more accurate to compare the chemical compositions of the two media for each particle size. Estimating the TC in this manner would eliminate the potentially confounding effect that some particle sizes may be preferentially transported into houses relative to other sizes.

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### Trademarks

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**Table 1: Estimated Transfer Coefficients**

Element	Dust Concentration (mg/kg)	Soil Concentration (mg/kg)	Transfer Coefficient	Source
*****	*****	*****	*****	*****
Al	19,000.0	66,000.0	0.2879	3
Al	25,000.0	71,000.0	0.3521	2, 5
Al	23,900.0	55,600.0	0.4299	1
Al	33,600.0	66,600.0	0.5045	4
Al	47,200.0	54,000.0	0.8741	4
Ce	23.6	52.3	0.4512	1
Ce	25.0	50.0	0.5000	2, 5
Fe	10,000.0	40,000.0	0.2500	2, 5
Fe	10,200.0	20,000.0	0.5100	1
Hf	2.0	6.0	0.3333	2, 5
Hf	2.1	4.1	0.5146	1
K	12,600.0	25,000.0	0.5040	1
K	13,000.0	14,000.0	0.9286	2, 5
La	10.0	40.0	0.2500	2, 5
La	11.9	27.4	0.4343	1
Mn	200.0	1,000.0	0.2000	2, 5
Mn	207.0	325.0	0.6369	1
Na	11,800.0	18,600.0	0.6344	1
Sc	2.9	6.8	0.4240	1
Sc	3.0	7.0	0.4286	2, 5
Sm	1.2	4.5	0.2667	2, 5
Sm	1.2	3.9	0.3128	1
Th	3.0	9.0	0.3333	2, 5
Th	3.4	8.2	0.4172	1
V	30.0	90.0	0.3333	2, 5
V	30.4	66.0	0.4606	1

**Sources**

1. Fergusson et al., 1986
2. Fergusson and Kim, 1991
3. Davis et al., 1990
4. Calabrese et al., 1989
5. Bowen, 1979

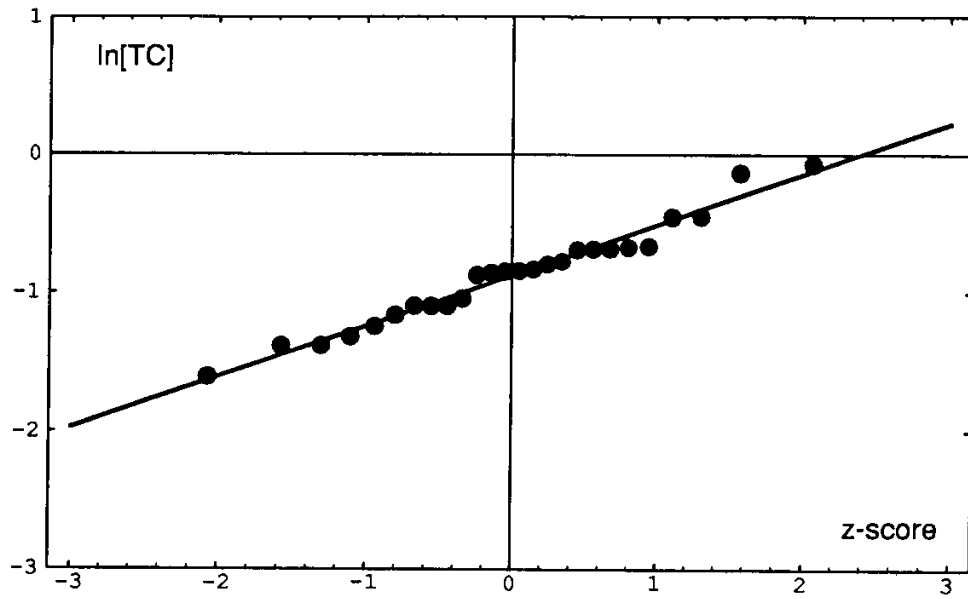


Figure 1

LogNormal Probability Plot for TC

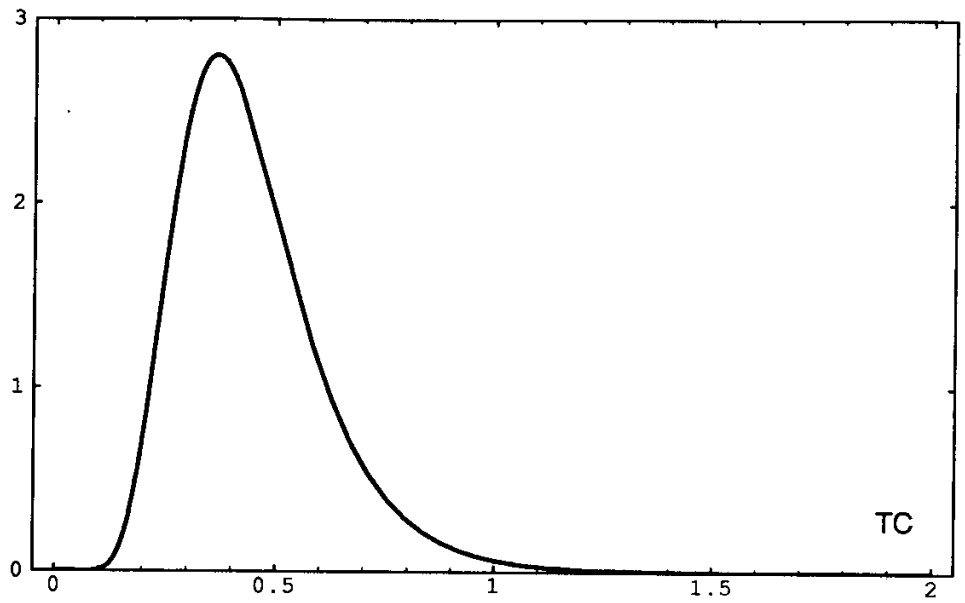


Figure 2

Probability Density Function for TC

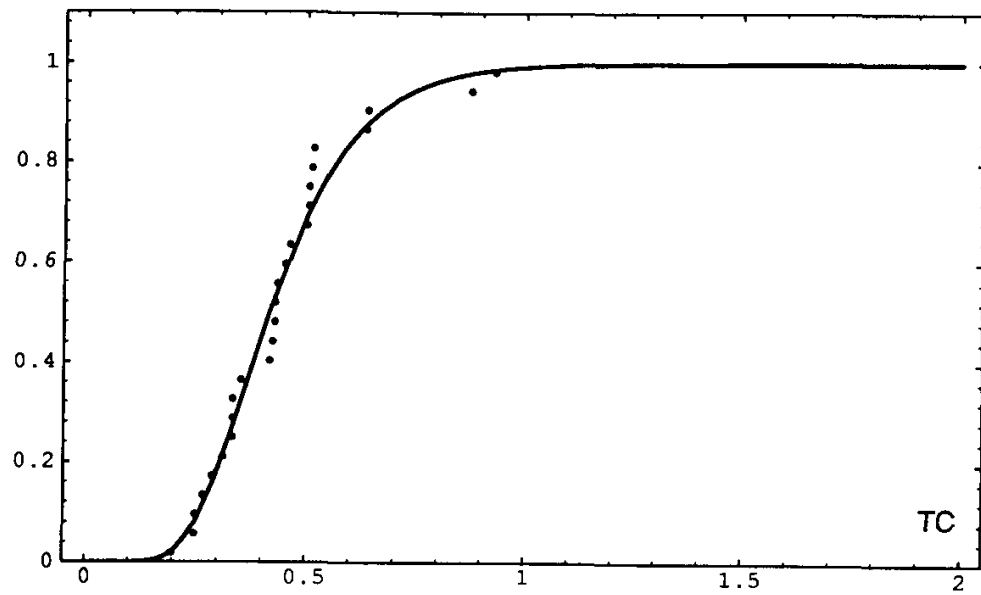


Figure 3

Cumulative Distribution Function for TC  
with data points superimposed