4 SOIL INGESTION

4.1 Introduction

There is general consensus that hand-to-mouth activity results in incidental soil ingestion, and children ingest more soil than adults. Soil ingestion rates vary depending on the age of the individual, frequency of hand-to-mouth contact, seasonal climate, amount and type of outdoor activity, the surface on which that activity occurs, and personal hygiene practices. The specified age ranges of interest in the “Hot Spots” program are ages third trimester<2, 0<2, 2<9, 2<16, 16<30 and 16-70 years.

At present, the knowledge of soil ingestion patterns within the United States is limited. A few researchers in the U.S. have attempted to quantify soil ingestion patterns in children, and have performed studies in a few locales mainly in the northern parts of the United States. The limited information shows that children may ingest fairly substantial amounts of soil on a per-kilogram-body-weight basis, and their soil ingestion pattern is important in understanding and estimating their overall exposures to environmental toxicants from contaminated soil.

The Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (ATSDR) has developed definitions for soil ingestion, soil-pica, and geophagy, to distinguish aspects of soil ingestion patterns that are important from a research perspective (ATSDR, 2001):

- ***Soil ingestion*** is defined as the intentional or unintentional consumption of soil. This may result from various behaviors including, but not limited to, mouthing, contacting dirty hands, eating dropped food, or consuming soil directly.
- ***Soil-pica*** is a form of intentional ingestion of unusually high amounts of soil (i.e., on the order of 1,000 - 5,000 milligrams per day).
- ***Geophagy*** is a form of soil ingestion defined as the intentional ingestion of earths usually associated with cultural practices.

The “soil” ingested could be from outdoor soil, containerized soil for indoor plants, or a combination of both. The soil ingestion recommendations in this document represent ingestion of combined “soil” and outdoor settled dust. Outdoor settled dust is derived from particles that deposited or settled on outdoor objects and surfaces. It is not possible to differentiate between soil and outdoor settled dust. The “dust” found indoors includes soil tracked inside the building or blown indoors through opened windows and doors, particles from building materials or consumer products, human and animal dander, and particles drawn in by the house’s heating and air conditioning system.

The source of “dust” in indoor environments can be quite variable. Many studies provided dust or soil ingestion estimates on pollutants that have both indoor and outdoor sources. For some pollutants it is often difficult to determine the percentage which each of these sources contributed to the amount of soil or dust ingested. Many pollutants emitted from stationary outdoor sources can also come from important indoor sources. For example, lead from lead paint is probably the major source of lead found in indoor dust. The contribution of lead emitted from stationary sources to indoor dust is probably minor compared to that from lead paint but is difficult to pinpoint. Thus, pollutants found in indoor dust from many studies may poorly reflect the amount contributed from stationary sources.

Soil ingestion has been documented in U.S. children and adults in several studies that use a "tracer element" methodology. The tracer element methodology attempts to quantify amounts of soil ingested by analyzing samples of soil from residences, and by analyzing samples of excreta (feces, and sometimes also urine). The soil, fecal, and urine samples are analyzed for the presence and quantity of tracer elements - typically, aluminum, silicon, titanium, and yttrium, and other elements. Because these metals/metalloids are not metabolized or absorbed to an appreciable extent in the gut, their presence in feces and urine can be used to estimate the quantity of soil ingested.

However, there is some evidence that tracer elements such as aluminum and silicon can be absorbed in small amounts from the digestive tract (Davis and Mirick, 2006). None of the studies using this methodology attempt to quantify amounts excreted in perspiration, tears, glandular secretions, shed skin, hair or nails. Entry into the body via the dermal and inhalation routes was not examined. Early studies usually did not account for the contribution of tracer elements from non-soil substances (food, medications, and non-food sources such as toothpaste) that children might swallow. Some studies adjusted the soil ingestion estimates to account for the potential contribution of tracer elements found in household dust as well as soil.

The amount of soil ingested is calculated from the quantity of the tracer element measured in the feces and urine minus that present in the food and medicine consumed. This number is then divided by the soil concentration of the tracer element to yield an estimate of ingested soil. Most of the studies assumed a lag time of 24 to 28 hours between ingestion and resulting fecal and urine output. Thus, the previous day’s food, medications and non-food quantity of the tracer element is subtracted from that found in the current day’s feces and urine excreted. An estimation of the amount of soil ingested daily can be obtained by dividing the total amount of soil ingested by the number of days in which the feces and urine were collected.

In the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008), U.S. EPA includes the “biokinetic model comparison” and “survey response” methods in the document to assess soil and dust ingestion in children. The biokinetic model methodology is used mainly to estimate children’s exposure to lead. This model compares lead exposure and uptake to predict children’s blood lead levels with biomarker blood measurements. The model predictions are made using assumptions about ingested soil and dust amounts that are based on the tracer element methodology. The survey response method uses the responses to survey questions regarding soil and dust ingestion. This method includes questions about children’s soil and dust ingestion behaviors, frequency, and sometimes the quantity ingested. The respondents are the children themselves, or their caregivers.

4.2 Soil Ingestion Recommendations

4.2.1 Incidental Soil Ingestion

Before 1997, the U.S. EPA (1989, 1991) used 200 mg/day as a soil ingestion rate for children one through six years of age. In 1997, in the *Exposure Factors Handbook*, U.S. EPA recommends 100 mg/day as a mean for children under six, but indicates 200 mg could be used as a conservative estimate of the mean as it is consistent with the data.

U.S. EPA (2008) in the *Child-Specific Exposure Factors Handbook* recommended values (central tendency, mg/d) for soil, and soil and dust combined of 30, 60 (age 6 to <12 months), 50, 100 (age 1 to <6 years), and 50, 100 (age 6 to <21 years), respectively. The 90th and 95th percentile values from the key studies were used together with other data to derive a number for pica soil ingestion (above 1000 mg/d). We think that it is not appropriate to assume that the 90th and 95th percentile values in the children's studies are due to pica behavior as in any group of children there will be those that will consume more soil than the average.

OEHHA supports the U.S. EPA (2008) recommendations of 100 mg/day as the central tendency of the combined soil and dust ingestion rate for children aged 1 to <6 years. This number was rounded down from the actual number of 110 mg/d. Using 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (Table 4-13), and assuming this group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Figure 4-17), soil and dust ingestion in other age groups are estimated (Table 4-18 and Table 4-19).

OEHHA calculated mean and 95th percentile soil and dust ingestions estimates (mg/kg BW-day) for the 3rd trimester < 2 by assuming that the soil and dust ingestions rate in mg/kg-day for the fetus was the same as for the mother (ages 16<30) and doing a time weighted average for the third trimester and ages 0 < 2.

OEHHA recommends the following point estimate soil and dust ingestion rates for children of various age groups and adults. Due to insufficient data, OEHHA has not developed distributions of soil ingestion data. Thus, this pathway is evaluated through the point estimate approach only.

Table 4.1 Recommended Soil Ingestion Estimates for Adults and Children (mg/kg-day)*

Age Groups (years)	Mean (mg/kg-day)	95^{th} % (mg/kg-day)
3rd Trimester[a]	0.7	3
0<2	20	40
2<9	5	20
2<16	3	10
9<16[b]	2	7
16<30	0.7	3
16 to 70	0.6	3
PICA children[c]	200	-
PICA adult	NR	-

The mean weights for various age groups (with exceptions, see below) are from Chapter 10, Table 10.8
[a] Assumed to be the mother's soil ingestion rate (adult age 16 <30)
[b] Estimated mean body weight for this age group 55 kg
[c] Estimated mean body weight used for the PICA children 30 kg
* Soil includes outdoor settled dust
NR = No recommendation

4.3 Algorithm for Dose from Soil Ingestion

4.3.1 Inadvertent Soil Ingestion by Adults and Children

The dose from inadvertent soil ingestion by adults can be estimated using the following general equation:

$$\text{DOSEsoil} = \text{Csoil} \times \text{GRAF} \times \text{SIR} \times \text{EF} \times (1 \times 10^{-9}) \qquad \text{(Eq. 4-1)}$$

where:

DOSEsoil = dose from soil ingestion (mg/kg body weight-day)
1×10^{-9} = conversion factor (μg to mg of contaminant, and kg to mg soil)
Csoil = concentration of contaminant in soil (μg/kg soil)
GRAF = gastrointestinal relative absorption fraction, unitless
SIR = soil ingestion rate (mg/kg BW-day)
EF = exposure frequency (days/year), EF = 350 d/yr (allows 2 week vacation away from residence)

The annual average soil concentration in the Hot Spots model is determined by air dispersion models and the half-life of the chemical in the soil. The term GRAF, or gastrointestinal relative absorption factor, is defined as the fraction of contaminant absorbed by the GI tract relative to the fraction of contaminant absorbed from the matrix (feed, water, other) used in the study(ies) that is the basis of either the cancer potency factor (CPF) or the reference exposure level (REL). If no data are available to distinguish absorption in the toxicity study from absorption from the environmental matrix in question, soil in this case, then the default assumption is that the GRAF = 1. The GRAF allows for adjustment for absorption from a soil matrix if it is known to be different from absorption across the GI tract in the study used to calculate the CPF or REL. At present that information is available only for polychlorinated dibenzo-p-dioxins and dibenzofurans. The GRAF for those compounds is 0.43. All others have a GRAF of 1.

The exposure frequency (EF) is the fraction of time spent at a residence or offsite work place, and is set at 350 days per year (i.e., per 365 days) to allow for two weeks per year away from home (US EPA,1991).

For cancer risk, the risk is calculated for each age group using the appropriate age sensitivity factors (ASFs) and the chemical-specific cancer potency factor (CPF), expressed in units of $(mg/kg\text{-}day)^{-1}$.

$$\text{RISKsoil} = \text{DOSEsoil} * \text{CPF} * \text{ASF} * \text{ED}/\text{AT} \qquad \textbf{(Eq. 4-2)}$$

Exposure duration (ED) is the number of years within the age groupings. In order to accommodate the use of the ASFs (see OEHHA, 2009), the exposure for each age grouping must be separately calculated. Thus, the DOSEsoil and ED are different for each age grouping. The ASF, as shown below, is 10 for the third trimester and infants 0<2 years of age, is 3 for children age 2<16 years of age, and is 1 for adults 16 to 70 years of age.

ED = exposure duration (yrs):

0.25 yrs for third trimester	(ASF = 10)
2 yrs for 0<2 age group	(ASF = 10)
7 yrs for 2<9 age group	(ASF = 3)
14 yrs for 2<16 age group	(ASF = 3)
14 yrs for 16<30 age group	(ASF = 1)
54 yrs for 16-70 age group	(ASF = 1)

AT, the averaging time for lifetime cancer risks, is 70 years in all cases. To determine lifetime cancer risks, the risks are then summed across the age groups:

$$\text{RISKsoil}_{(\text{lifetime})} = \text{RISKsoil}_{(\text{3rdtri})} + \text{RISKsoil}_{(0<2\text{ yr})} + \text{RISKsoil}_{(2<16\text{ yr})} + \text{RISKsoil}_{(16\text{-}70\text{yr})} \qquad \textbf{(Eq. 4-3)}$$

As explained in Chapter 1, we also need to accommodate cancer risk estimates for the average (9 years) and high-end (30 years) length of time at a single residence, as well as the traditional 70 year lifetime cancer risk estimate. For example, assessing risk in a 9 year residential exposure scenario assumes exposure during the most sensitive period, from the third trimester to 9 years of age and would be presented as such:

$$\text{RISKsoil}_{(\text{9-yr residency})} = \text{RISKsoil}_{(\text{3rdtri})} + \text{RISKsoil}_{(0<2\text{ yr})} + \text{RISKsoil}_{(2<9\text{ yr})} \qquad \textbf{(Eq. 4-4)}$$

For 30-year residential exposure scenario, the 2<16 and 16<30 age group RISKsoil would be added to the risks for third trimester and age 0<2. For 70 year residential risk, Eq 4-3 would apply.

As described earlier, children have been divided into the following age groups with respect to soil ingestion rate: 0 to <2 years, 2 to <9 years, and 2 to <16 years of age. In addition, soil ingestion estimates are calculated for the adult age groups, 16 to < 30 years, and 16 to 70 years of age. In Section 4.7, OEHHA recommends soil ingestion rates for the 9, 30 and 70 year exposure duration scenarios.

The exposure duration scenarios evaluate the first 9, 30 and 70 years of an individual's life. The evaluation of the 9, 30 and 70 year exposure durations represent central tendency, ≈90th- 95th and lifetime of residency time, respectively. The evaluation of the 0 to <2 years, 2 to <9 years, 9 < 16 years, 16 to < 30 years, and 30 to 70 years age groupings are needed in order to properly estimate cancer risk for the age ranges as specified in *The Technical Support Document for Cancer Potency Factors: Methodologies for Derivation, Listing of Available Values, and Adjustments to Allow for Early Life Stage Exposures* (OEHHA, 2009).

For children, OEHHA is recommending that 9.7, 21.9, and 37.0 kg be used for the body weight for the 0 to <2, 2 to <9 and 2 to <16 year-old groups, respectively, for determination of dose from soil ingestion (Chapter 10). For the 16 to <30 and 16 to 70 year exposure duration scenarios, OEHHA recommends that 75.9 and 80.0 kg body weight, respectively, be used for the body weight term (Chapter 10). These body weights have been incorporated into the recommended soil consumption rates (mg/kg body weight-day). Care should be taken in using the appropriate ED and EF values for each sub-age grouping. Pica children are analyzed separately as described in Section 4.6.

4.3.2 Inadvertent Soil Ingestion by Offsite Workers

The impact zone of a facility may include offsite workplaces. Risk estimates for those offsite workers include exposure from incidental soil ingestion for multi-pathway chemicals. Equation 4-3 can be used, but the exposure is adjusted for the time at work by multiplying by 5/7 days, and 46/70 years (a total adjustment of 0.15). This adjustment is meant to account for soil ingestion occurring while at work. The assumption inherent in the exposure adjustment is that one third of the daily soil ingestion occurs at work. For those who work outdoors this assumption may underestimate exposure, and could be an overestimation for those who work mainly indoors.

4.4 Soil Intake - Key Children Studies

4.4.1 Davis and Co-workers Studies

4.4.1.1 Davis et al. (1990)

In this study, 104 toilet-trained children between the ages of 2 and 7 years were randomly recruited from a three-city area in southeastern Washington State. The study was conducted over a seven day period, primarily during the summer. A mass-balance/tracer technique was used to estimate soil ingestion. Daily soil ingestion was evaluated by analyzing soil and house dust, feces, urine, and duplicate food samples for aluminum, silicon, and titanium. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil intake rates among children. The soil intake rates were corrected for the amount of tracer in vitamins and medications.

Soil ingestion rates were highly variable, especially those based on titanium. Mean daily soil ingestion estimates were 39 mg/day for aluminum, 82 mg/day for silicon and 246 mg/day for titanium (Table 4-2). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. The differences in concentrations of the tracer elements in house dust and yard soil were adjusted to estimate soil ingestion rates.

Table 4.2 Soil Ingestion Values From Davis et al. (1990)

Tracer Element[a]	Mean (mg/d)	Median (mg/d)	Standard Error of the Mean(mg/d)	Range(mg/d)[b]
Aluminum	38.9	25.3	14.4	279.0 to 904.5
Silicon	82.4	59.4	12.2	-404.0 to 534.6
Titanium	245.5	81.3	119.7	-5,820.8 to 6,182.2

a Excludes three children who did not provide any samples (n=101).

b Negative values occurred as a result of correction for non-soil sources of the tracer elements.

The adjusted mean soil/dust intake rates were 65 mg/day for aluminum, 160 mg/day for silicon, and 268 mg/day for titanium. Adjusted median soil/dust intake rates were: 52 mg/day for aluminum, 112 mg/day for silicon, and 117 mg/day for titanium.

The soil ingestion range includes negative numbers, which is indicative of a basic difficulty in estimating soil ingestion rates using the mass balance approach. If fecal output does not correspond to the food/medicines sampled due to factors such as the variation in transit time in the gut, then the calculated soil ingestion rate will be inaccurate. Overcorrecting for the presence of tracer elements in foods and medicines can bias the soil ingestion estimates downward, producing negative soil ingestion estimates which are obviously impossible. Likewise, if the food that was digested to produce the fecal sample contained more tracer elements than the food that was sampled, the soil ingestion rate can be biased in the positive.

In addition, the following demographic characteristics were found to be associated with high soil intake rates: male sex, racial groups other than white, low income, operator/laborer as the principal occupation of the parent, and city of residence. However, none of these factors were predictive of soil intake rates when tested using multiple linear regression.

Although a relatively large sample population was surveyed, these children were all from a single area of the U.S. and may not be representative of the U.S. population as a whole. The study was conducted over a one-week period during the summer and may not be representative of long term (i.e., annual) or seasonal patterns of soil intake.

4.4.1.2 Davis and Mirick, 2006

The study used a subset of the 104 families who participated in the soil ingestion study by Davis *et al.* (1990). The data for this study were collected one year prior to the Davis *et al.* (1990) study. Nineteen families were selected in this study. Each family consisted of one child participant between the age of 3 and 7, and one female and one male parent or guardian living in the same house. Samples were collected for 11 consecutive days of all food items consumed, all feces excreted, twice-daily urine, and soil/house dust. Tracer elements for this study included aluminum, silicon and titanium. In addition, parents completed a daily diary of the activities for 4 consecutive days for themselves and the participant child during the study period.

For children, the mean and median estimates for all three tracers ranged from 36.7 to 206.9 mg/day and 26.4 to 46.7 mg/day, respectively, and fall within the range of those reported by Davis *et al.* (1990). Adult soil ingestion estimates ranged from 23.2 to 624.9 mg/day for mean values and from 0 to 259.5 mg/day for median values, and were more variable than for the children in the study regardless of the tracer element used. The authors believed that this higher variability in adult soil ingestion rates may be attributed to occupational exposure in some, but not all, of the adults. Similar to the Davis *et al.* (1990) study, the soil ingestion estimates were the highest for titanium.

Various behaviors were found to be associated with increased soil ingestion in this study such as reported eating of dirt (for children), occupational contact with soil (for adults), and hand washing before meals (for both children and adults). Within the same family, a child's soil ingestion was not found to be associated with the parent's soil ingestion, nor did the mother and father's soil ingestion appear to be correlated. Although toothpaste is a known source of titanium, the titanium content of the toothpaste used by study participants was not determined.

An advantage of this study is that it examines soil ingestion among children and adults in the same family. However, the sample population was small and the families were a subset of those in a previous study, chosen for their high compliance to the study protocol. Thus, the uncertainties from the previous study still exist.

Table 4.3 Soil Ingestion Values From Davis and Mirick (2006)

Participant	Tracer Element	Estimated Soil Ingestion (mg/day)[a]			
		Mean	Median	Standard Deviation	Maximum
Child[b]	Aluminum	36.7	33.3	35.4	107.9
	Silicon	38.1	26.4	31.4	95.0
	Titanium	206.9	46.7	277.5	808.3
Mother[c]	Aluminum	92.1	0	218.3	813.6
	Silicon	23.2	5.2	37.0	138.1
	Titanium	359.0	259.5	421.5	1394.3
Father[d]	Aluminum	68.4	23.2	129.9	537.4
	Silicon	26.1	0.2	49.0	196.8
	Titanium	624.9	198.7	835.0	2899.1

[a] For some study participants, estimated soil ingestion resulted in a negative value. These estimates have been set to 0 mg/day for tabulation and analysis.
[b] Results based on 12 children with complete food, excreta, and soil data.
[c] Results based on 16 mothers with complete food, excreta, and soil data.
[d] Results based on 17 fathers with complete food, excreta, and soil data.

4.4.2 Binder and Co-workers Study

4.4.2.1 Binder et al. (1986)

Binder *et al.* (1986) used a tracer technique modified from a method previously used to measure soil ingestion among grazing animals to study the ingestion of soil among children. The children were studied during the summer of 1984 as part of a larger study of residents living near a lead smelter in East Helena, Montana.

Binder *et al.* (1986) measured tracer elements in feces to estimate soil ingestion by young children 1 to 3 years of age who wore diapers. Soiled diapers collected over a three day period from 65 children (42 males and 23 females), and composite samples of soil obtained from 59 of these children's yards were analyzed for aluminum, silicon, and titanium. It was assumed that the soil ingested by these children originated largely from their own yards. The soil tracer elements were assumed to be minimally absorbed in the GI tract and minimally present in the children's diet. Soil ingestion by each child was estimated based on an assumed fecal dry weight of 15 g/day. Tracer elements were assumed to be neither lost nor introduced during sampling.

Daily soil ingestion rates based on aluminum, silicon and titanium are presented in Table 4.4. The minimum soil ingestion presented in the table is based on the lowest of three estimates of soil ingestion in each subject. The minimum is presented because of the failure to account for the presence of the three tracers in ingested foods, medicines, and other sources such as toothpaste. Estimates from aluminum and silicon were comparable. However, much higher soil ingestion estimates were obtained using titanium as a tracer suggesting that there may be an unrecognized source of titanium that the children were ingesting or the tracer element was introduced during the laboratory processing of stool samples.

Table 4.4 Soil Ingestion Rates (mg/day) From Binder et al. (1986)

Tracer:	Aluminum	Silicon	Titanium
Mean	181	184	1834
Standard deviation	203	175	3091
Range	25-1324	31-799	4-17,076
Median	121	136	618
95th percentile	584	578	9590
Geometric mean	128	130	401

The advantages of this study are that a relatively large number of children were studied and tracer elements were used to estimate soil ingestion. However, there were several methodological difficulties with the protocol pointed out by the investigators. The tracers ingested in foods and medicines were not accounted for which leads to overestimation of soil ingestion rates. Rather than using measured fecal weights, the investigators assumed a dry fecal weight of 15 g/day for each child. This may lead to either over- or underestimation of soil ingestion rates. Measuring fecal weights was difficult because the entire diaper (including urine) was collected, and as much stool as possible recovered from the diaper.

This was a short-term study and, as with all the studies on soil ingestion rates, the data may not be entirely representative of longer-term soil ingestion rates. Finally, the children may not be a representative sample of the U.S. population.

4.4.3.1 Amherst, Massachusetts Studies

4.4.3.1.1 Calabrese et al. (1989)

Sixty-four children between one and four years old in the Amherst, Massachusetts area were studied. Soil ingestion rate was based on measurements of eight tracer elements: aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium, and a method similar to Binder *et al.* (1986) but including a mass balance approach was used. Duplicate meal samples, including vitamins and medicines, were collected for all children from Monday through Wednesday of two consecutive weeks, while fecal and urine samples were collected over four 24-hour periods from noon Monday through noon Friday in the corresponding weeks.

Soil and dust samples were collected from each child’s home and play areas. Children were given toothpaste, diaper rash ointment and other hygiene products that contained trace to no levels of the tracer elements. Blanks of diaper and commode specimens using distilled water were collected to control for introduced tracer. Waste samples from a single 24-hour period were pooled as were soil samples which represented composite samples from the three areas in which the child played the most.

In addition, these investigators also provided a validation study in six adult volunteers, age 25-41, for three consecutive days (Monday to Wednesday, breakfast and dinner) for three weeks. The volunteers ingested empty gelatin capsules in week one, gel capsules containing 50 mg sterilized soil in week two, and gel capsules containing 250 mg soil in week three. Duplicate food samples were collected as in the children's study and total excretion was collected Monday through Friday for the three study weeks. Soil was determined to be non-contaminated in terms of priority pollutants and contained enough of each tracer element to be detectable in the excreta.

The adult validation study indicated that study methodology could adequately detect soil ingestion at rates expected by children. The ingestion of soil in the second week was accompanied by a marked increase in fecal excretion of tracer that could not be accounted for by variability of tracer in food. Recovery data from the adult study indicated that aluminum, silicon, yttrium, and zirconium had the best recoveries (closest to 100%) while barium and manganese grossly exceeded 100% recovery. Both these elements were deemed unreliable due to their relatively higher concentrations in food relative to soil. Zirconium as a tracer was highly variable and titanium was not reliable in the adult studies. The investigators conclude that aluminum, silicon, and yttrium are the most reliable tracers for soil ingestion. Also see description of Calabrese *et al.* (1990).

The results of the soil ingestion calculations for children based on excretory tracer levels minus food tracer levels (Table 4.5) indicate a median value between 9 mg/day for yttrium and 96 mg/day for vanadium. There was a large degree of interindividual variation, with one or two extreme outliers. The mean estimates were considerably higher than the median in most cases.

Table 4.5 Soil Ingestion Results (mg/day) for Children Aged 1 to 4 Years from Calabrese et al. (1989)

Tracer:	Aluminum	Silicon	Titanium	Vanadium	Yttrium	Zirconium
Mean	153	154	218	459	85	21
Median	29	40	55	96	9	16
SD	852	693	1150	1037	890	209
95th %	223	276	1432	1903	106	110
Max	6837	5549	6707	5676	6736	1391

One child in this study exhibited pica behavior. The high soil ingestion rates for this child may or may not be applicable to other soil pica children or, over time, even to this one child. However, it is interesting to note that this study did pick up a child with this behavior.

There are a number of methodological difficulties in attempting to quantify soil ingestion using the tracer methodology. Food (including vitamins and medicines), soil, and fecal material are analyzed for specific tracer elements in a mass balance approach to estimate soil ingestion. The assumption is that the tracer elements measured in the feces are exclusively from the food and medicines analyzed. However, transit time through the gut varies widely. The fecal sample may not represent the food/medicine sample input. This input-output misalignment can underestimate soil ingestion and could result in negative soil ingestion estimates.

The other main type of error in tracer studies for estimating soil ingestion is source error. Source error occurs when an unknown or unaccounted for source of the tracer element is ingested by the study subjects. The soil ingestion estimate can be inflated since it is assumed that soil is the source of tracer.

However, this study is useful in several ways. The mass balance approach attempts to correct for ingestion of tracer such as titanium in foods, medicines, and toothpaste. The validation regimen in adults points out the most reliable tracers and validates the overall methodology. The complete sample collection of urine and feces in this study obviates the need to assume a fecal weight for calculating soil ingestion estimates. A relatively large population was studied, but it may not be entirely representative of the U.S. population because it was selected from a single location. The results presented in this paper have been superseded by more refined analyses of the same data by the authors (Stanek and Calabrese, 1995a and 1995b).

4.4.3.1.2 Calabrese and Stanek (1992)

This study estimated the amount of outdoor soil in indoor dust using statistical modeling. Data from 60 homes in the Calabrese *et al.* (1989) study were used to develop scatter plots of each tracer concentration in soil (outdoor) versus dust (indoor) for the subject population. The scatter plots show little evidence of a consistent relationship between outdoor soil and indoor dust concentrations.

The assumption is that 50% of excess fecal tracers were from indoor origin. Multiplying this by the model prediction that 31.3% of indoor dust came from outdoor soil resulted in an estimate that 15% of excess fecal tracers were from soil material present in indoor dust. These analyses indicate that approximately 65% of the total fecal tracer was of soil origin and the estimates of median outdoor soil ingestion presented in the earlier study should be reduced by 35%. The revised soil ingestion estimates are reduced from 29 to19 mg/d based on aluminum, 40 to 26 mg/d based on silicon, and 9 to 6 mg/d based on yttrium.

The model uses several simplifying assumptions: a) the amount of dust produced every day from both indoor and outdoor sources in a house is constant for all houses, b) the proportion of indoor dust due to outdoor soil is constant for all houses, and c) the concentration of the tracer element in dust produced from indoor sources is constant for all houses. The validity of these assumptions cannot be evaluated and subsequent papers by the authors did not make use of this adjustment.

4.4.3.1.3 Stanek and Calabrese (1995a)

Stanek and Calabrese (1995a) reanalyzed the soil ingestion study by Calabrese *et al.* (1989). The individual daily soil ingestion estimates (64 subjects for 8 days) were used to develop distributions of values for 365 days for each subject using an assumed lognormal distribution. All soil ingested was assumed to come from outdoors and food intake was directly linked with fecal output. Daily soil ingestion estimates were made for each element and each study subject. The study links the food samples with the fecal samples in an attempt to more accurately estimate soil ingestion rates. In addition, the tracers were ranked according to their usefulness, and criteria for excluding certain soil ingestion estimates were incorporated into the reanalysis.

Negative estimates were replaced with a value of 1 mg/day. For each day and subject, medians, and lower and upper bounds of soil ingestion rate were calculated for the eight tracers. The lower and upper bounds functioned as exclusion criteria. If a soil ingestion rate estimate fell outside the bounds, it was assumed to be invalid and discarded. The investigators took estimates of the means and medians of the subjects' daily soil ingestion and constructed their cumulative distributions.

The results indicate that mean soil ingestion estimates over the study period of four to eight days were 45 mg/day or less for 50% of the children and 208 mg/day or less for 95% of the children. The median daily soil ingestion estimates were 13 mg/day or less for 50% of the children studied, and 138 mg/day or less for 95% of the children studied.

The median of the distribution of average daily soil ingestion extrapolated over 365 days is 75 mg, while the 95th percentile is 1751 mg/day. The median of the distribution of median soil ingestion estimates is 14 mg/day while the 95th percentile is 252 mg/day. The range of upper 95th percentiles of the median soil ingestion rate estimates for 63 kids (exclusive of the one pica child) is 1 to 5623 mg/day.

Stanek and Calabrese (1995a) also evaluated the presence of soil pica using their distribution methodology. They estimated that on 35-40 days of the year, 16% of children would ingest more than 1 gram/d of soil and 1.6% would ingest more than 10 grams/d.

Table 4.6 Estimates of Children (%) Exceeding Certain Soil Ingestion Rates from Stanek and Calabrese (1995a)

Soil Ingestion Rate	**Days per year of excessive soil ingestion**		
	1-2	7-10	35-40
> 1 gram	63%	41%	16%
> 5 grams	42%	20%	1.6%
>10 grams	33%	9%	1.6%

There are many limitations to the study, one of which is the assumption of lognormal distributions to estimate daily soil ingestion over 365 days. There is little empirical evidence to support its use. The number of samples needed to capture typical intake over a year would be considerably more and seasonal variability would need to be taken into account. There are methodological difficulties in quantifying the distribution of soil ingestion rates such as assuming that the transit time in the gut was the same for all subjects and did not vary within subjects. The correction used is unlikely to be adequate to account for the input-output misalignment error, probably resulting in the negative soil ingestion estimates as obtained in Calabrese *et al.* (1989).

There are large discrepancies between trace elements estimates of soil ingestion for the same subject on the same day. The outlier criterion was used to correct for the likelihood that ingestion of some tracers occurred from other sources than food or soil. The exclusion methodology (using the median as a reference point rather than the mean) did not indicate how many data points were excluded or what those data points were. However, the effect of these exclusions is probably small as indicated by comparing the distributions of the mean estimates (where three or fewer elements are used following exclusion) with the distribution of the mean estimates (where no elements are excluded).

Short term studies are often all that are available to extrapolate to long term intakes needed for risk assessment. However, the limitations need to be acknowledged and the data available must be sufficient to perform the quantification.

4.4.3.1.4 Stanek and Calabrese (1995b)

Stanek and Calabrese (1995b) reanalyzed the data from their 1989 study with data from Davis *et al.* (1990) using a different methodology from that used in Stanek and Calabrese (1995a). The Best Tracer Method (BTM), based on the food to soil ratio, is designed to overcome inter-tracer inconsistencies in the estimation of soil ingestion rates. It is assumed that tracers with a low food to soil ratio lead to more precise soil ingestion estimates because confounding from the tracer content of food is decreased.

The combined data from the two studies (Calabrese *et al.* 1989 and Davis *et al.* 1990) were used to construct estimates of the food to soil (F/S) ratio for each trace element for each subject/week. The F/S ratio was calculated by dividing the average daily amount of a trace element ingested from food by the soil trace element concentration per gram soil. For each subject/week, these ratios were ranked lowest to highest. The F/S ratio is small when the tracer concentration in food is almost zero compared to the tracer concentration in soil. A small F/S ratio is desirable because it lessens the impact of transit time error. This error occurs when fecal output does not reflect food ingestion, due to fluctuation in gastrointestinal transit time. Distributions of soil ingestion estimates are presented based on the various ranked tracers for both children (Calabrese *et al.* 1989; Davis *et al.* 1990) and adults (Calabrese *et al.* 1990).

In contrast to the Stanek and Calabrese (1995a) study, negative values for soil ingestion estimates were included in the distributions. This would shift the distribution towards lower ingestion estimates. While it is valuable to eliminate source error as much as possible by utilizing elements with low F/S ratios, the presence of negative soil ingestion estimates is indicative that there still is a problem with input-output misalignment. Negative soil ingestion estimates are biologically meaningless, and incorporating these values into a distribution is problematic. Distributions of soil ingestion estimates from the combined studies for children are presented in Table 4.7.

Table 4.7 Distributions of Soil Ingestion Estimates (mg/d) in Children from Stanek and Calabrese (1995b)

Studies	Percentiles						Mean ± SD	Min	Max
	10th	25th	50th	90th	95th	99th			
A[a]	-6	9	33	110	154	226	132 ± 1006	-97	11,415
B[b]	-52	-15	44	210	246	535	69 ± 146	-404	905
A and B	-12	10	37	156	217	535	104 ± 758	-404	11,415

Table based on element groupings formed by ranked food:soil ratios.

[a] Study A: data from Calabrese et al., 1989

[b] Study B: data from Davis et al., 1990

Based on the 64 children in the Calabrese *et al.* (1989) study and using the median soil ingestion estimates from the best four tracers, the mean soil ingestion rate was 132 mg/day and the median soil ingestion rate was 33 mg/day. The 95th percentile value was 154 mg/day. For the 101 children in the Davis *et al.* (1990) study, the mean soil ingestion rate was 69 mg/day and the median soil ingestion rate was 44 mg/day. The 95th percentile estimate was 246 mg/day. When the Calabrese *et al.* (1989) and Davis *et al.* (1990) studies were combined, soil ingestion rates for children were estimated to be 104 mg/day (mean), 37 mg/day (median) and 217 mg/day (95th percentile), using the BTM. When the adult data from the Calabrese *et al.* (1990) study were reevaluated, soil ingestion rates were estimated to be 64 mg/day (mean), 87 mg/day (median), and 142 mg/day (95th percentile), using the BTM.

This study combines data from two studies of children, one from southwestern Washington and one from Massachusetts, thus increasing the number of observations. It also corrects for some differences associated with tracer metabolism. The limitations associated with the data used in this study are the same as the limitations described earlier in the summaries of the Calabrese *et al.* (1989), Davis *et al.* (1990) and Calabrese *et al.* (1990) studies.

4.4.3.2 Anaconda, Montana Studies

4.4.3.2.1 Calabrese et al. (1997)

Sixty-four children ages 1-3 years and predominantly from two-parent households living on a Superfund site in Anaconda, Montana were selected for this study. Thirty-six of the 64 children were male, and the children ranged in age from 1 to 3 years with approximately an equal number of children in each age group. The study was conducted for seven consecutive days during a two week period in the month of September.

Duplicate samples of meals, beverages, and over- the-counter medicines and vitamins were collected over the seven day period, along with fecal samples. In addition, soil and dust samples were collected from the children's home and play areas. Toothpaste containing non-detectable levels of the tracer elements, with the exception of silica, was provided to all of the children. Infants were provided with baby cornstarch, diaper rash cream, and soap which were found to contain low levels of the tracer elements. The mass-balance methodology similar to that in Calabrese *et al.* (1989) was used.

As in Calabrese *et al.* (1989), an additional study was conducted in which the mass-balance methodology was used on adults in order to validate that soil ingestion could be detected. Known amounts of soil were administered to ten adults (5 males, 5 females) from Western Massachusetts over a period of 28 days. Each adult ingested for 7 consecutive days: a) no soil during Week 1, b) 20 mg of sterilized soil during Week 2, c) 100 mg of sterilized soil during Week 3, and d) 500 mg of sterilized soil during Week 4. Duplicate food and fecal samples were collected every day during each study week and analyzed for the eight tracer elements (aluminum, silicon, titanium, cerium, lanthanum, neodymium, yttrium, and zirconium). The authors determined that a soil ingestion of 200 to 500 mg/day could be detected in a reliable manner.

Soil ingestion by each tracer element was estimated using the Best Tracer Method (BTM), which allows for the selection of the most recoverable tracer for a group of subjects (Stanek and Calabrese, 1995b). The median soil ingestion estimates for the four best trace elements based on food:soil ratios for the 64 children are presented in Table 4-8. The best estimate was calculated by taking the median of these four trace elements. Based on the soil ingestion estimate for the best tracer, the mean soil ingestion rate was 66 mg/day and the median was 20 mg/day. The 95th percentile value was 283 mg/day. Using the median of the 4 tracers, the mean was 7 mg/day and the 95th percentile was 160 mg/day.

These results are lower than the soil ingestion estimates obtained by Stanek and Calabrese (1995a). The investigators believed that families, who participated in this study, were aware that they lived on an EPA Superfund site and this knowledge might have resulted in reduced exposure. There was no statistically significant difference found in soil ingestion estimates by gender or age, by housing or yard characteristics (i.e., porch, deck, door mat, etc.), or between children with or without pets.

The advantages of this study were a consecutive seven day study period rather than two periods of 3 and 4 days (Stanek and Calabrese, 1995a), the use of the BTM, and the use of a dietary education program to reduce food tracer input and variability.

Table 4.8 Soil Ingestion Estimates for 64 Anaconda Children (mg/day) Based on Food:Soil Ratios for Aluminum, Silicon, Titanium, Yttrium, and Zirconium [b]

Tracer	Soil Ingestion (mg/day)[a]										
	Percentile							Min	Max	Mean	SD
	5th	10th	25th	50th	75th	90th	95th				
Median[b]	-91.0	-53.8	-38.0	-2.4	26.8	73.1	159.8	-101.3	380.2	6.8	74.5
Best	-24.4	-14.4	2.2	20.1	68.9	223.6	282.4	-53.4	609.9	65.5	120.3
2nd best	-62.1	-48.6	-26.6	1.5	38.4	119.5	262.3	-115.9	928.5	33.2	144.8
3rd best	-88.9	-67.0	-52.0	-18.8	25.6	154.7	376.1	-170.5	1293.5	31.2	199.6
4th best	-171.0	-131.9	-74.7	-29.3	0.2	74.8	116.8	-298.3	139.1	-34.6	79.7

[a] Negative values occurred as a result of calculating child-specific estimates for multiple days. For example, negative estimates of soil ingestion occurred when an individual child had low, but positive, soil ingestion, but the standard deviation was large.

[b] Median value of best four tracers

Table 4.9 Dust Ingestion Estimates for 64 Anaconda Children (mg/day) Based on Food/Dust Ratios for Aluminum, Silicon, Titanium, Yttrium, and Zirconium [b]

Tracer	Dust Ingestion (mg/day)[a]										
	Percentile							Min	Max	Mean	SD
	5th	10th	25th	50th	75th	90th	95th				
Median[b]	-186.2	-152.7	-69.5	-5.5	62.8	209.2	353.0	-261.5	683.9	16.5	160.9
Best	-193.8	-91.0	-20.8	26.81	198.1	558.6	613.6	-377.0	1499.4	127.2	299.1
2nd best	-147.2	-137.1	-59.1	7.6	153.1	356.4	409.5	-239.8	1685.1	82.7	283.6
3rd best	-247.5	-203.1	-81.7	-14.4	49.4	406.5	500.5	-375.7	913.2	25.5	235.9
4th best	-365.6	-277.7	-161.5	-55.1	52.4	277.3	248.8	-542.7	6120.5	81.8	840.3

[a] Negative values occurred as a result of calculating child-specific estimates for multiple days. For example, negative estimates of dust ingestion occurred when an individual child had low, but positive, dust ingestion, but the standard deviation was large.

[b] Median value of best four tracers.

However, the data presented in this study are from a single seven-day period during September which may not reflect soil ingestion rates for longer time-periods or other seasonal months. The net residual negative error indicates probably an underestimation in the soil ingestion rates. The investigators estimated that this error is unlikely to affect the median value by more than 40 mg/day. Since the data from half of the distribution are negative, it is difficult to place a lot of confidence in the soil and dust ingestion estimates obtained.

4.4.3.2.2 Calabrese et al. (1996)

In this study Calabrese *et al.*, (1996) examined the hypothesis that differences in soil tracer concentrations could be related to soil particle size. Soil that was used by Calabrese *et al.* (1997) from Anaconda, Montana was reanalyzed for the tracer concentration after it had been sieved to a particle size of <250 µm in diameter (<2 mm soil particle size in the original study). The smaller particle size was examined based on the assumption that children and adults principally ingest soil of small particle size adhering to fingertips and under fingernails.

Soil concentration was not changed by particle size for five of the tracers used in the original study (aluminum, silicon, titanium, yttrium, and zirconium). However, the soil concentrations of three tracers (cerium, lanthanum and neodymium) were increased two- to four-fold at the smaller soil particle size. Soil ingestion estimates for these three tracers were decreased by approximately 60% at the 95th percentile, when the effect of particle size on tracer concentration is taken into account.

4.4.3.2.3 Stanek et al. (1999)

Stanek *et al.* (1999) extended the findings from their earlier study (Calabrese *et al.* 1996) by quantifying trace element concentrations in soil of different particle sizes. The soil was sieved to particle sizes of 100 to 250 µm and to particle sizes of 53 to < 100 µm. This study used the data from soil concentrations from the Anaconda, Montana site reported by Calabrese *et al.* (1997).

Results of the study indicated that soil concentrations of aluminum, silicon, and titanium did not increase at the two finer particle size ranges measured. However, soil concentrations of cerium, lanthanum and neodymium increased by a factor of 2.5 to 4.0 in the 100-250 µm particle size range when compared with the 0 to 2 µm particle size range. There was not a significant increase in concentration in the 53 to 100 µm particle size range. The importance of this study and that published in 1996 is that they provide further insights regarding the selection of tracers for soil ingestion studies.

4.4.3.2.4 Stanek and Calabrese (2000)

In this study the soil ingestion data from the Anaconda, Montana study were reanalyzed, assuming a lognormal distribution for the soil ingestion estimates. Average soil ingestion for children was predicted over time periods of 7 days, 30 days, 90 days, and 365 days. The 95th percentile soil ingestion values predicted were 133 mg/day over 7 days, 112 mg/day over 30 days, 108 mg/day over 90 days, and 106 mg/day over 365 days. Based on this analysis, estimates of the distribution of longer term average soil ingestion are expected to be narrower, with the 95th percentile estimates being as much as 25% lower. The limitations to this analysis were similar to that discussed in Stanek and Calabrese (1995a) in Section 4.4.3.1.3.

4.4.4 Clausing and Co-workers Studies

4.4.4.1 Clausing et al. (1987)

This soil ingestion study was conducted with Dutch children using the Limiting Tracer Method (LTM). Aluminum, titanium, and acid-insoluble residue (AIR) contents were determined for fecal samples from children aged 2 to 4 years attending a nursery school and for samples of playground dirt at that school.

Twenty seven daily fecal samples were obtained over a 5-day period for the 18 children examined. Using the average soil concentrations present at the school, and assuming a standard fecal dry weight of 10 g/day, soil ingestion was estimated for each tracer. Eight daily fecal samples were also collected from six hospitalized, bedridden children. These children served as a control group, representing children who had little access to soil. The average quantity of soil ingested by the school children in this study was 230 mg/day (range 23 to 979 mg/day) for aluminum; 129 mg/day (range 48 to 362 mg/day) for AIR; and 1,430 mg/day (range 64 to 11,620 mg/day) for titanium. As in the Binder et al. (1986) study, a fraction of the children (6/19) showed titanium values well above 1,000 mg/day.

Table 4.10 Soil Ingestion Results (mg/day) From Clausing et al. (1987)

	School Children	Hospitalized Children	Difference
Mean	105	49	56
Standard Deviation	67	22	
Range	23-362	26-84	
Geometric Mean	90	45	

Mean soil intake for the school children was estimated to be 105 mg/day with a standard deviation of 67 mg/day (range 23 to 362 mg/day). Geometric mean soil intake was estimated to be 90 mg/day. The soil intake for this group of children was much higher when compared to the hospitalized children used as the control group (mean 49 mg/day, standard deviation 22 mg/day).

Mean (arithmetic) soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum. For titanium, three of these children had estimates well in excess of 1,000 mg/day, with the remaining three children in the range of 28 to 58 mg/day. The mean soil ingestion rate was estimated to be 49 mg/day with a population standard deviation of 22 mg/day (range 26 to 84 mg/day). The geometric mean soil intake rate was 45 mg/day (Table 4-10).

The data on hospitalized children suggest a non-soil source of titanium and aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered. Assuming that soil ingestion rates observed in hospitalized children actually represent background tracer intake from dietary and other non-soil sources, mean soil ingestion by nursery school children was estimated to be 56 mg/day (i.e., 105 mg/day for nursery school children minus 49 mg/day for hospitalized children).

The advantages of this study are that the investigators evaluated soil ingestion among children that had differences in access to soil and soil intake rates were corrected based on background estimates derived from the hospitalized group. However, the number of children used in this study was small. Tracer elements in foods or medicines were not evaluated. Also, the study was a short-term study and the intake rates may not be representative of soil intake over the long-term. The children's activities were not monitored. For example, hand washing frequency could impact soil ingestion.

4.4.4.2 Van Wïjnen et al. (1990)

In this study soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using the tracer element methodology (LTM) used by Clausing *et al.* (1987). Three tracers (titanium, aluminum, and acid insoluble residue (AIR)) were measured in soil and feces and soil ingestion was estimated from the measurements. An average daily feces dry weight of 15 g was assumed. A total of 292 children attending daycare centers were sampled during the first sampling period and 187 children were sampled in the second. A total of 78 children were sampled at campgrounds. Samples taken from 15 hospitalized children were used as controls.

The mean soil ingestion values for these groups were: 162 mg/day for children in daycare centers, 213 mg/day for campers and 93 mg/day for hospitalized children. Geometric means were estimated to be 111 mg/day for children in daycare centers, 174 mg/day for children vacationing at campgrounds and 74 mg/day for hospitalized children (70-120 mg/day based on the 95th percent confidence limits of the mean) (Table 4-11). AIR was the limiting tracer in about 80 percent of the samples. Among children attending daycare centers, soil intake was also found to be higher when the weather was good.

The investigators used the mean value (93 mg/day) for hospitalized children as the background intake of tracers. Using the mean value to correct the soil intake rates, corrected soil intake rates were 69 mg/day for daycare children and 120 mg/day for campers. Corrected geometric mean soil intake was estimated to range from 0 to 90 mg/day with a 90th percentile value of 190 mg/day for the various age categories within the daycare group and 30 to 200 mg/day with a 90th percentile value of 300 mg/day for the various age categories within the camping group.

The major limitation of this study is that tracer concentrations in food and medicine were not evaluated. Although the population of children studied was relatively large, it may not be representative of the U.S. population. This study was conducted over a relatively short time period and estimated intake rates may not reflect long-term patterns, especially at the high-end of the distribution. Another limitation of this study is that values were not reported element-by-element, and the children's daily activities such as hand washing frequency were not monitored.

Table 4.11 Soil Ingestion Values Using the LTM Methodology for Children at Daycare Centers and Campgrounds

Age (Years)	Sex	Daycare centers			Campgrounds		
		N	Geometric Mean(mg/d)	Geometric Standard Deviation(mg/d)	N	Geometric Mean(mg/d)	Geometric Standard Deviation(mg/d)
birth to <1	**Girls**	3	81	1.09	-	-	-
	Boys	1	75	-	-	-	-
1 to <2	**Girls**	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2 to <3	**Girls**	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3 to <4	**Girls**	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4 to <5	**Girls**	1	180	-	19	164	1.48
	Boys	4	99	1.62	18	136	1.30
CombinedAll ages	**Girls**	86	117	1.70	36	179	1.679
	Boys	72	104	1.46	42	169	1.7
Total		162[a]	111	1.60	78[b]	174	1.73

[a] Age and/or sex not registered for eight children.

[b] Age not registered for seven children.

4.4.5 Other Relevant Studies and Analyses

4.4.5.1 Thompson and Burmaster (1991)

Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the key study data collected by Binder *et al.* (1986). In the original Binder *et al.* (1986) study, an assumed dry fecal weight of 15 g/day was used. Thompson and Burmaster re-estimated the soil ingestion rates from the Binder *et al.* (1986) study using the actual stool weights of the study participants instead of the assumed stool weights. Because the actual stool weights averaged only 7.5 g/day, the soil ingestion estimates presented by Thompson and Burmaster (1991) are approximately one-half of those reported by Binder *et al.* (1986).

The mean soil intake rates were 97 mg/day for aluminum, 85 mg/day for silicon, and 1,004 mg/day for titanium. The 90th percentile estimates were 197 mg/day for aluminum, 166 mg/day for silicon, and 2,105 mg/day for titanium. Based on the arithmetic average of aluminum and silicon for each child, mean soil intake was estimated to be 91 mg/day and 90th percentile intake was estimated to be 143 mg/day (Table 4-12).

Table 4.12 Distribution of Soil Ingestion Estimates For Children by Thompson and Burmaster (1991)

	Soil Intake (mg/d)			
	Aluminum	**Silicon**	**Titanium**	**Mean[a]**
Mean	97	85	1004	91
Median	45	60	293	59
90th %	197	166	2105	143

[a] Arithmetic average of soil ingestion based on aluminum and silicon

Thompson and Burmaster (1991) also adjusted Binder *et al.* (1986) data for aluminum, and silicon for lognormal distribution. No adjustment was made for titanium because titanium may be present in high concentrations in food and the Binder *et al.* (1986) study did not correct for food sources of titanium. Statistical tests indicated that only silicon and the average of the silicon and aluminum tracers were lognormally distributed.

The advantages of this study are that it provides percentile data and defines the shape of soil intake distributions. However, the number of data points used to fit the distribution was limited. This analysis is based on a study that did not correct for tracer intake from food or medicine and the methodological difficulties encountered in the original Binder *et al.* study still exist including difficulty in obtaining the entire fecal sample from a diaper.

4.4.5.2 Sedman and Mahmood (1994)

The data of two previous studies, Calabrese *et al.* 1989 and Davis *et al.* 1990, were used to obtain estimates of the average daily soil ingestion in young children. The soil ingestion in these children was determined by dividing the excess tracer intake (the quantity of tracer recovered in the feces in excess of the measured intake) by the average concentration of tracer in soil samples from each child's dwelling.

The mean estimates of soil ingestion in children for each tracer were adjusted from both studies to reflect that of a 2-year old child. The mean of the adjusted levels of soil ingestion for a two year old child was 220 mg/kg for the Calabrese *et al.* (1989) study and 170 mg/kg for the Davis *et al.* (1990) study. Based on a normal distribution of means, the mean estimate for a 2-year old child was 195 mg/day. Based on uncertainties associated with the method employed, the authors recommended a conservative estimate of soil ingestion in young children of 250 mg/day. Based on the 250 mg/day ingestion rate in a 2-year old child, a lifetime intake was estimated to be 70 mg/day.

4.4.5.3 Calabrese and Stanek (1995)

Calabrese and Stanek (1995) examined the various sources and magnitude of positive and negative errors in soil ingestion estimates for children.

Possible sources of positive errors include:

a) ingestion of high levels of tracer elements before the start of the study and low ingestion during the study period, and
b) ingestion of tracer elements from a non-food or non-soil source during the study period.

Possible sources of negative bias include:

a) ingestion of tracer elements in food, but they are not captured in the fecal sample either due to slow transit time or not having a fecal sample available on the final study day, and
b) diminished detection of tracer element levels in fecal, but not in soil samples.

The data of Calabrese *et al.* (1989) were quantified to reduce the magnitude of error in the individual trace element ingestion estimates. A lag period of 28 hours was assumed for the passage of tracers ingested in food to the feces. A daily soil ingestion rate was estimated for each tracer for each 24-hr day fecal sample. Daily soil ingestion rates for tracers that fell beyond the upper and lower ranges were excluded from subsequent calculations, and the median soil ingestion rates of the remaining tracer elements were considered the best estimate for that particular day.

The positive and negative errors for six tracer elements from the 1989 Calabrese *et al.* study were estimated. The original mean soil ingestion rates ranged from a low of 21 mg/day based on zirconium to a high of 459 mg/day based on titanium. The adjusted mean soil ingestion rate after correcting for negative and positive errors ranged from 97 mg/day based on yttrium to 208 mg/day based on titanium.

The authors concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion. However, this approach is based on the hypothesis that the median tracer value is the most accurate estimate of soil ingestion, and the validity of this assumption depends on the specific set of tracers used in the study. The estimation of daily tracer intake is the same as in Stanek and Calabrese (1995a), and the same limitations mentioned earlier in Calabrese *et al.*(1989) still exist.

4.4.5.4 Stanek et al. (2001)

The authors developed a simulation model to identify and evaluate biasing factors for soil ingestion estimates from data taken from Calabrese *et al.* (1989), Davis *et al.* (1990), and Calabrese *et al.* (1997). Only the data from the aluminum and silicon trace element estimates were used.

Study duration has the most positive bias in all the biasing factors explored, with a bias of more than 100% for the 95th percentile estimates in the 4-day mass balance study. A smaller bias was observed for the impact of absorption of trace elements from food. Although the trace elements selected for use in the mass balance studies are believed to have low absorption, the amount unaccounted for will result in an underestimation of the soil ingestion distribution. In these simulations, the absorption of trace elements from food of up to 30% was shown to negatively bias the estimated soil ingestion distribution by less than 20 mg/day.

4.4.5.5 Zartarian et al. (2005)

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates using data from several studies as input for the Stochastic Human Exposure and Dose Simulation (SHEDS) model for the U.S. EPA. Data from Calabrese's Amherst and Anaconda studies (Calabrese *et al.* 1989, 1997) were used to fit distributions of soil/dust ingestion rates. The statistical distributions relied upon two tracers only, aluminum and silicon, in estimating the parameters of the lognormal variability and uncertainty distributions.

Using a Monte-Carlo sampling method, values from the fitted distribution were separated into those values under 500 mg/day and values that exceeded 500 mg/day. Soil ingestion values that exceed 500 mg/day are assumed to represent pica behavior. Using the SHEDS model, the soil ingestion rate distribution for non-pica behavior children has a mean of 61, standard deviation of 81, median of 30, 95th percentile of 236, and 99th percentile of 402 (mg/day). For children exhibiting pica behavior, the mean is 962, standard deviation 758, median 735, 95th percentile 2130, and 99th percentile 3852 (mg/day).

A limitation of this analysis is that pica children and incidental ingestion were simulated separately. The distribution for incidental soil ingestion does not take into account that children may have days where they ingest unusually high levels of soil, which may not be indicative of long-term pica behavior.

4.4.5.6 Hogan et al. (1998)

Hogan *et al.* (1998) published a paper that compares observed and predicted children's blood lead levels as applied to the Integrated Exposure and Uptake Biokinetic (IEUBK) model for lead in children. The IEUBK model is being used by the U.S. EPA and state regulatory agencies as a model for lead uptake from environmental media for risk assessments. The model functions primarily to estimate the risk and probability of children having blood lead concentrations exceeding a specific level of concern. It predicts children's blood levels by using measurements of lead in house dust, soil, drinking water, food and air together with default inputs such as child-specific estimates of intake for each exposure medium.

One of the parameters that the IEUBK model uses to estimate child blood lead concentration is the ingestion of soil and household dust. Young children are primarily exposed to lead through fine particles of surface soil and household dust that adhere to their hands and are incidentally ingested during normal hand-to-mouth activities. The age-specific default soil and dust ingestion rates recommended for use in the IEUBK model (version 0.99d) are 50 and 60 mg/day (averaged over children ages 1 through 6), respectively. The combined soil and dust ingestion is 110 mg/day. The default soil ingestion values used in the IEUBK model are based on several observational studies by Binder *et al.* (1986), Clausing *et al.* (1987), Calabrese *et al.* (1989, 1991), van Wijnen *et al.* (1990) and Davis *et al.* (1990), utilizing the trace element methodology (U.S. EPA, 1994).

Hogan *et al*. (1998) applied an empirical comparisons exercise of the IEUBK method to evaluate three epidemiologic datasets consisting of blood lead levels of 478 children. These children were a subset of the entire population of children living in three historic lead smelting communities: Palmerton, Pennsylvania; Southern Kansas/southwestern Missouri; and Madison County, Illinois. The children's measured blood lead levels were compared with the IEUBK's blood lead predictions using measured lead levels in drinking water, soil and dust together with the model's default inputs such as soil/dust ingestion rates and lead bioavailability.

Results showed that there was reasonably close agreement between observed and IEUBK predicted blood lead distributions in the three studies. The geometric means for the observed and predicted blood lead levels were within 0.7 µg/dl. U.S. EPA (2008) used this study to do a back calculation on the soil and dust ingestion rates and concluded that the numbers (50 mg/d soil; 60 mg/d dust; and 110 mg/d combined) are "roughly accurate in representing the central tendency soil and dust ingestion rates" of children ages 1 to 6.

4.4.6 U.S. EPA (2008)

The U.S. EPA (2008) *Child-Specific Exposure Factors Handbook* considered certain studies as "key" for developing recommendations for children's soil ingestion rates. Key tracer element methodology, biokinetic model comparison, and survey response studies were selected based on judgment about the study's design features, applicability, and utility of the data to U.S. children, clarity and completeness, and characterization of uncertainty and variability in ingestion estimates. Most of the key studies selected are the same as those described in this Section.

The soil ingestion recommendations represented ingestion of a combination of soil and outdoor settled dust. The dust ingestion recommendations included soil tracked into indoor environment, indoor settled dust and air-suspended particulate matter that is inhaled and swallowed. The recommended values for soil and dust are on a dry weight basis.

The recommended central tendency soil and dust ingestion for infants 6 months up to their first birthday is 60 mg/d (soil 30 mg/d, dust 30 mg/d), and for children ages 1 to <6 years is 100 mg/d (soil 50 mg/d, dust 60 mg/d, sum rounded to 100 mg/d). In the absence of data that can be used to develop specific central tendency soil and dust ingestion recommendations for children aged 6 to <11 years, 11 to <16 years and 16 to

<21 years, U.S. EPA (2008) recommends using the central tendency soil and dust ingestion rate of 100 mg/d developed for children ages 1 to <6 years. An important factor is that the recommendations did not extend to issues regarding bioavailability of the contaminants present in the soil and dust.

Table 4.13 Recommended Values for Daily Soil and Dust Ingestion From U.S. EPA (2008)

Age Group	Central Tendency Values, mg/day		
	Soil	Dust	Soil and Dust
6 to <12 m	30	30	60
1 to <6 y	50	60	100[a]
6 to <21 y	50	60	100[a]

[a] Sum of 110 mg/d rounded to one significant figure

Adapted from Child-Specific Exposure Factors Handbook, U.S. EPA (2008)

4.5 Soil Ingestion Adult Studies

There are few studies that estimated adult soil ingestion. The three studies that provide data used in the estimation of soil ingestion in adults did not provide the ages of the individuals studied. They were not designed as adult soil ingestion studies but rather as a validation of the methodology used to study soil ingestion in children.

4.5.1 Hawley (1985)

Hawley (1985) suggested a value of 480 mg/day for adults engaged in outdoor activities, a range of 0.6 to 110 mg/day of house dust during indoor activities, and an annual average of 60.5 mg/day. These estimates were derived from assumptions about soil/dust levels on hands, mouthing behavior, and frequencies of certain indoor and outdoor activities, without supporting measurements.

4.5.2 Calabrese et al (1990)

This study was originally part of the study in children in Calabrese *et al.* (1989). The soil ingestion rates for the 6 volunteer adults were estimated by subtracting out the tracer quantities in food and soil capsules from the amounts excreted. The four most reliable tracers were aluminum, silicon, yttrium, and zirconium. Median soil ingestion rates were as follows: aluminum, 57 mg; silicon, 1 mg; yttrium, 65 mg; and zirconium, -4 mg. Mean values were: aluminum, 77 mg; silicon, 5 mg; yttrium, 53 mg, and zirconium, 22 mg. The average of the soil ingestion means based on the four tracers is 39 mg. The sample size is very small (n = 6) and the study was not designed to look at soil ingestion by the adults but rather as a validation of the overall soil ingestion tracer methodology.

4.5.3 Stanek and Calabrese (1995b)

Stanek and Calabrese (1995b) reanalyzed the data from their 1989 study of children with data from Davis *et al.* (1990), and their adult study (Calabrese *et al.* 1990) using the Best Tracer Method (BTM). Distributions of soil ingestion estimates were based on the various ranked tracers for both children and adults. A description of this study is provided in Section 4.4.3. When the adult data from the Calabrese *et al.* (1990) study were reevaluated, soil ingestion rates were estimated to be 64 mg/day (mean), 87 mg/day (median), and 142 mg/day (95th percentile), using the BTM.

4.5.4 Stanek et al. (1997)

Soil ingestion was evaluated in 10 adults as part of a larger study to evaluate soil ingestion in children. The average daily soil ingestion (taken over 4 weeks) was 6 mg/day. The estimation was based on four tracer elements aluminum, silicon, titanium, and zirconium, although 8 tracers were measured. The authors reported that “the broad range in estimates for different trace elements implies that a simple average estimate (over the eight trace elements) provides little insight into adult soil ingestion, since estimates based on different trace elements for the same adults and time periods are so highly variable”. To account for variability and bias, the authors decided to base the estimate of soil ingestion on trace elements whose concentrations in soil are relatively homogeneous across different particle sizes. Trace elements that satisfied this criterion include aluminum, silicon, titanium, yttrium and zirconium, and they were considered for estimating soil ingestion by the authors.

However, this study has some complications. One of the ten adults in the study had a high soil ingestion estimate (2 grams) on the first day. The subject also had 4 times higher freeze-dried fecal weight than on any day of the study suggesting that this may be due to days of fecal accumulation. The result is an inflated 95th percentile soil ingestion estimate.

Calabrese (2003) recommended that the upper 75th percentile estimate soil ingestion of 49 mg/day be used as an estimate of high-end soil ingestion by adults (letter to the General Electric Company concerning the U.S. EPA’s Human Health Assessment for the Housatonic River) (Calabrese *et al.* 2003). Although the outlier subject in the study causes the 95th percentile soil ingestion estimate to be inflated, it should not be ignored as enhanced adult ingestion could occur among agricultural or utility workers. The study itself also shows that there are problems in the use of tracers and the results varied depending upon which set of tracers was used.

4.5.5 Davis and Mirick (2006)

This study estimated soil ingestion in children aged 3 to 8 years and their parents (16 mothers and 17 fathers) for 11 consecutive days. Three trace elements (Al, Si, and Ti) were measured. The ages of the adults were not provided.

Since titanium exhibits much greater variability compared to other tracer elements due to its presence in various non-soil sources, only Al and Si were used to estimate the adult daily soil ingestion. The means of the mothers and fathers are calculated to be 58 and 47 mg/day, respectively. The weighted average for the combined adults is 53 mg/day.

Table 4.14 Adult Soil Ingestion Estimates from Davis and Mirick (2006)

Tracer Element	**Mean Adult Soil Ingestion (mg/day)**	
	Mothers	**Fathers**
Al	92.1	68.4
Si	23.2	26.1
Mean	57.7	47.3
Mean of All Adults	52.5	

4.5.6 Summary of Adult Soil Ingestion Estimates

The mean and 95th percentile adult soil ingestion rates are calculated from the studies as shown in Table 4-15. For soil ingestion in adults, the average of the mean and the 95th percentile are 41 and 213 mg/day, respectively.

Table 4.15 Summary of Soil Ingestion Estimates (mg/day) in Adults

Study	**Mean**	**P95**
Calabrese et al (1990) and Stanek and Calabrese (1995b)	64	142
Stanek et al (1997)	6	331
Davis and Mirick (2006)	53	168[a]
Average	41	213

[a] The 95th percentile adult soil ingestion from Davis and Mirick (2006) was calculated from data in the paper assuming lognormal distribution.

4.6 PICA

4.6.1 General Pica

General pica is the repeated eating of non-nutritive substances including sand, clay, paint, plaster, hair, string, cloth, glass, matches, paper, feces, and various other items (Feldman, 1986). There are numerous reports on general pica among various populations and this behavior appears to occur in approximately half of all children between 1-3 years of age (Sayetta, 1986). Danford (1982) reported that the incidence of general pica was higher for black children (30%) than for white children (10-18%) between 1-6 years of age. There appears to be no sex differences in the incidence rates (Kaplan and Sadock, 1985).

However, general pica is reported to be higher among children in lower socioeconomic groups (50-60%) than in higher income families (about 30%) and is more common in rural areas (Lourie *et al.* 1963, Vermeer and Frate, 1979). A higher rate of general pica has also been reported in pregnant women, individuals with poor nutritional status, and mentally retarded children (Behrman and Vaughan 1983, Danford 1982, Illingworth 1983, Sayetta 1986).

General pica does not include the consumption of some condiments that contain clay or soil. Examples are the Hawaiian Red Alaea sea salt (containing the red volcanic clay called Alaea) and black sea salt found in many parts of the world (containing lava and other substances). These salts have characteristic taste and are used in cooking and food preservation.

4.6.2 Soil Pica

ASTDR (2001) defines soil pica as the recurrent ingestion of unusually high amounts of soil of between 1,000 - 5,000 mg/day. Bruhn and Pangborn (1971) studied dirt ingestion in migrant agricultural workers among 91 non-black, low-income families in California. The incidence of pica was 19% in children, 14% in pregnant women, and 3% in non-pregnant women. However, in this study “dirt” was not clearly defined and may include non-soil substances.

Data from tracer studies (Binder *et al.*, 1986; Clausing *et al.,* 1987; Van Wïjnen *et al.*, 1990; Davis *et al.*, 1990; and Calabrese *et al.*, 1989) showed that only one child out of the more than 600 children studied ingested soil in significantly large amounts to indicate pica behavior. In addition, parental observations regarding children who are likely to be high soil ingesters were reported to be often inaccurate (Calabrese *et al.*, 1997).

A study by Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., intentional earth eating) was about 16% among children from a rural black community in Mississippi. In this study, the intentional earth eating was described as a cultural practice in the community surveyed and may not be representative of the general population. However, there are cultures in many parts of the world where soil eating is practiced in religious or sacred rituals.

4.6.3 Soil Pica Behavior in Children

Information on the amount of soil ingested by children with pica behavior is very limited. There is no study on pica children and infrequent pica behavior is often observed in normal children in soil ingestion studies.

4.6.3.1 Calabrese et al. (1991); Calabrese and Stanek (1992)

Calabrese *et al.* (1991) reported a pica child among the 64 children who participated in the soil ingestion study. One 3.5-year-old female child had extremely high soil ingestion, from 74-2200 mg/day during the first week and from 10.1-13.6 g/day during the second week of observation. The upper soil ingestion values for this pica child range from approximately 5 to 7 g/day.

Using a methodology that compared differential element ratios, Calabrese and Stanek (1992b) quantitatively attempt to distinguish outdoor soil ingestion from indoor dust ingestion in this pica child. Using tracer ratios of soil, dust, and residual fecal samples, an analysis was performed which indicates that from 71 to 99% of the tracer originated from soil. The authors concluded that the predominant proportion of the fecal tracers originated from outdoor soil and not from indoor dust.

4.6.3.2 Wong (1988) as reviewed by Calabrese and Stanek (1993)

Wong (1988) in his doctoral thesis studied soil ingestion by 52 children in two government institutions in Jamaica. This study was reviewed by Calabrese and Stanek (1993). The younger group contained 24 children with an average age of 3.1 years (range of 0.3 to 7.6 years). The older group contained 28 children with an average age of 7.2 years (range of 1.8 to 14 years).

Fecal samples were obtained from the children and the amount of silicon in dry feces was measured to estimate soil ingestion. An unspecified number of daily fecal samples were collected from a control group consisting of 30 hospital children with an average age of 4.8 years (range of 0.3 to 12 years). Dry feces were observed to contain 1.45% silicon, or 14.5 mg Si per gram of dry feces. This quantity was used as a baseline representing the background level of silicon ingestion from dietary sources. Observed quantities of silicon greater than 1.45% were interpreted as originating from soil ingestion.

For the 28 children in the older group, soil ingestion was estimated to be 58 mg/day, based on the mean minus one outlier, and 1520 mg/day, based on the mean of all the children. The outlier was a child with an estimated average soil ingestion of 41 g/day over the 4-month period. This child was stated to be “developmentally disabled”, but no information was provided on the nature or severity of the disability. Of the 28 children in the group, 7 had average soil ingestion greater than 100 mg/day, 4 had average soil ingestion greater than 200 mg/day, and one had average soil ingestion greater than 300 mg/day. Eight children showed no indication of soil ingestion. The mean soil ingestion of all the children was 470 ± 370 mg/day.

Of the 24 children in the younger group, 14 had average soil ingestion of less than 100 mg/day, 10 had average soil ingestion greater than 100 mg/day, 5 had average soil ingestion greater than 600 mg/day, and 4 had average soil ingestion greater than 1000 mg/day. Five children showed no indication of soil ingestion. Of the 52 children studied, 6 displayed soil pica behavior.

The use of a single soil tracer in this study may introduce error in the sampling because there may be other sources of the tracer in the children's environment. For example, certain types of toothpastes have extremely high silica concentrations, and children may ingest significant quantities during brushing. Silica may also be found in indoor dust that children could ingest. Despite these uncertainties, the results indicate that soil pica is not a rare occurrence in younger children in this study population. Results from this Jamaica study may not be indicative of similar behavior in children in the United States.

4.6.3.3 ATSDR (2001)

ATSDR (2001) held a workshop to discuss and review the state of the science on soil pica behavior. The review acknowledges that soil pica clearly exists, but there were insufficient data to determine the prevalence of this behavior in children and in adults. The present ATSDR assumption that soil pica children ingest 5 g of soil/day is supported by only a few subjects (i.e., two children in Massachusetts and six children in Jamaica). The ATSDR (2001) committee advises ATSDR to err on the side of being health protective and to continue using the 5 g/day pica ingestion number until more data become available.

4.6.3.4 Zartarian et al. (2005)

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates from several studies in the literature using the Stochastic Human Exposure and Dose Simulation (SHEDS) model of the U.S. EPA. Data from Calabrese's Amherst and Anaconda studies were used to fit distributions of soil/dust ingestion rates. A soil pica distribution was obtained by sampling from the fitted lognormal distribution and retaining values above 500 mg/day. The mean and 95th percentile values for this population were estimated to be 963 mg/day and 2170 mg/day, respectively (See Section 4.4.5.6).

4.6.3.5 U.S. EPA (1984)

In a risk assessment for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) in an investigation on the exposure potential to 2,3,7,8-TCDD via soil ingestion used a value of 10 g/day to represent the amount of soil that a child with pica behavior might ingest (Kimbrough *et al.,* 1984). These values are based on only one pica child observed in the Calabrese *et al.* (1989) study where the intake ranged from 10-14 g/day during the second week of observation. The CDC suggests that an ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information.

4.6.3.6 U.S. EPA (2008)

In the 2008 U.S. EPA's *Child-Specific Exposure Factors Handbook*, U.S. EPA redefined children's "soil-pica" as the quantity of soil ingested by children above 1000 mg/d. Using this definition, the upper 90th and 95th percentiles of soil ingestion from all the key primary studies were included in the assessment of children's pica soil ingestion. The soil-pica ingestion estimate for children up to age 14 ranged from 400 to 41,000 mg/d. The recommended value for soil pica in children was then set at 1000 mg/day. No data were available for individuals above 14-21 years. We believe this number is probably too low based on our calculations (see Table 4.16).

4.6.3.7 Summary of Pica Behavior Studies in Children

Soil ingestion in 8 children that exhibited pica behavior from two studies is given in Table 4-16. It is important to note that soil pica behavior in children in the studies used was observed over a very short period of time and may not reflect long-term pica behavior. In the absence of data, the ATSDR panelists recommended in the *Summary Report for the ATSDR Soil-Pica Workshop* (2001) that "ATSDR should err on the side of being protective and should use 5000 mg until more data are collected". We concur with this recommendation. Our calculation on pica children in two studies shows that the amount ingested is about 5000 mg/day (Table 4-16).

Table 4.16 Pica Behavior in Children

Sample Size	Observation (days)	Age	Soil Ingestion (mg/day)	Source
1 1	2 4	2.5 -	20,000; 22,000 1000-2000	Calabrese et al. (1989, 1991)
1 1 1 1 1	1 1 "different days" "different days" 1	3.1[a]	1447 7924 1016; 2690; 898 10343; 4222; 1404; 5341 5341	Wong (1988) doctoral thesis. Study reviewed and presented by Calabrese and Stanek (1993)
1[c]	"different days"	7.2[b]	48,300; 60,692; 51,422; 3782	Wong (1988) doctoral thesis. Study reviewed and presented by Calabrese and Stanek (1993)

Number of Children	Average Pica Soil Ingestion (mg/day)
8	10,600
7[d]	5500

[a] Average age of 24 children

[b] Average age of 28 children

[c] This child was stated to be "developmentally disabled" by the author

[d] Excluding last child

4.6.4 Soil Pica Behavior In Adults

The ASTDR report (2001) views adult soil pica to be an extremely rare behavior that has not been characterized. Deliberate consumption of clays or soil (geophagy) has been reported in many parts of the world and is particularly prevalent among certain cultural groups especially during certain rituals or religious ceremonies. However, the clay or soil is typically from known uncontaminated sources. Thus, surface soils are generally not the source of geophagical materials consumed. Very little data are available to establish an unintentional soil ingestion rate for adults with pica behavior.

4.7 Hand-To-Mouth Transfer

The studies discussed earlier examined soil intake using a mass balance methodology that measures trace elements in feces and soil. These studies have various shortcomings one of which is the paucity of data for estimating soil ingestion to a broader age range in children and adults. Data are lacking for children less than 1 and above 7 years of age, and for adults where ages are often not given in the studies.

U.S. EPA (2005) provides guidance on the appropriate age groups to consider when assessing children's exposure and potential dose of environmental contaminants. The recommended childhood age groups for exposure and risk assessments are: birth to <1 month, 1 to < 3 months, 3 to < 6 months, 6 to < 12 months, 1 to < 2 years, 2 to < 3 years, 3 to < 6 years, 6 to < 11 years, 11 to < 16 years, 16 to < 18 years, and 18 to < 21 years. These age groupings take into consideration human developmental and physiological changes that impact exposure and potential dose intake. Hand-to-mouth activities may provide information that may be useful in assessing the ingestion of soil in age groups that do not have direct soil ingestion data.

4.7.1 Hand-to-Mouth Transfer Behavior in Children

Children often put their hands, toys, and other objects in their mouths during normal exploration of their environment, as a sucking reflex and as a habit. This hand-to-mouth behavior may result in the ingestion of soil and dust, from outside and/or indoors. Transfer from the hand to the mouth can occur directly by handling of contaminated soil and indirectly by using products, materials and equipment that come in contact with contaminated soil. This can happen in both occupational and non-occupational settings. Soil ingestion can occur by touching the mouth with the hand, nail biting, finger sucking, eating food (especially with bare hands), smoking cigarettes, and other hand-to-mouth activities.

Generally, children's mouthing behavior is studied using both direct observation and videotaping methodologies (Zartarian *et al.* 1998; Reed *et al.* 1999; Freeman *et al.* 2001, 2005; AuYeung *et al.* 2006, 2008; Black *et al.* 2005; Ferguson *et al.* 2005). Observations may be conducted by an instructed parent, or by a trained person. Videotaping the child's behavior is usually done by a trained technician, and information from these recordings is obtained by a trained person who watches the videotapes.

4.7.2 Probabilistic Models of Hand-to-Mouth Transfer

Estimation of non-dietary ingestion of a chemical via hand-to-mouth contact includes information of the hand residue/soil loading (µg/cm² or µg/g), hand-to-mouth frequency (number of contacts/hr), area of hand surface mouthed (cm²), and exposure duration (hr/day). Probabilistic models have been developed to estimate non-dietary ingestion of a chemical via hand-to-mouth contact (e.g., Calendex™ by Exponent Inc.; CARES™ by International Life Science Institute; Lifeline™ by Lifeline Group; and Residential-SHEDS by U.S. EPA's Office of Research and Development).

These models have certain limitations as the calculations are based on data from the few studies available on non-dietary ingestion via hand-to-mouth contact. The studies used in the models have their own limitations such as the different methods of data collection, analysis and reporting, different age groupings of research subjects, and even different definition of "mouthing". Models such as SHEDS that deal with various microenvironments assume a strong relationship between the total dust ingested and indoor dust loading. Although the ratio of ingested outdoor soil to ingested indoor dust is important, factors influencing exposure and risk such as the types of exposures, chemical pollutants indoors and outdoors, amount of track-in, resuspension and particle size, seasonal effects, and fate and transport are some of the issues still largely uncharacterized.

4.7.3 Relevant Hand-to-Mouth Transfer Studies (Summary)

Studies that provide estimates for a hand load transfer factor or transfer efficiency include the analyses of Dubé *et al.* (2004), Beyer *et al.* (2003), and the report from the Consumer Product Safety Commission (CPSC, 2003).

4.7.3.1 Dubé et al. (2004)

Using data from Stanek and Calabrese (1995a), Dubé *et al.* (2004) estimated the fraction of "dislodgeable" residue on the hands of children that was incidentally ingested daily. The estimate was 25% hand load per day (range: 7 – 100%) for 2 to 6 year olds, and 13% hand load per day (range: 3.5 – 50%) for 7 to 31 year olds. This assumed that individuals 7 years old and up would ingest half the amount of soil as 2 to 6 year olds. Information was not provided for a direct hand-to-mouth transfer factor for soil, the fraction of material on the hand in contact with the mouth that is transferred, the number of hand to mouth contacts, and losses through intermediate contacts.

4.7.3.2 Beyer et al. (2003)

Beyer *et al* (2003), in their assessment of incidental ingestion of metals from laundered shop towels in the workplace, used a value of 13% as the fraction dislodged from the hands that was incidentally ingested on a daily basis by adults.

4.7.3.3 CPSC (2003)

The Consumer Product Safety Commission (CPSC, 2003) developed an estimate of the percent of residue dislodged on the hands that is ingested on a daily basis by children. The estimate was based on data on soil ingestion, soil–skin adherence, and contact surface area of the hand with soil from multiple studies. There are large uncertainties in the available data analyzed. The daily intake estimates for children ranged from 3% to 700% of the mass loaded on the hand (i.e., “handload”), with an average of 43% for both direct and indirect hand-to-mouth activities combined.

4.7.3.4 Zartarian et al. (2000)

Zartarian *et al.* (2000) used the U.S. EPA’s Residential Stochastic Human Exposure and Dose Simulation (Residential-SHEDS, 2000) model for pesticides to estimate children’s exposure to chlorpyrifos. The primary purpose of the study is to demonstrate the capabilities of the model by simulating the exposures and doses of children who contacted chlorpyrifos residues inside treated residences and on turf-treated residential yards. The hand-to-mouth transfer efficiency of chlorpyrifos was estimated to range from 10% to 50%, based on the data of Zartarian *et al.* (1997); Leckie *el al.* (1999); Kissel *et al.* (1998) and Camann *et al.* (2000). The 50% hand-to-mouth transfer efficiency has been used by the CPSC (1997) in estimating hand-to-mouth exposure to lead from polyvinyl chloride products, and by the U.S. EPA’s Office of Pesticide Programs as a default value for hand-to-mouth exposure to pesticides (U.S. EPA, 2001).

4.7.3.5 Zartarian et al. (2005)

Zartarian *et al.* (2005) working under a contract from the U.S. EPA derived a statistical distribution for hand-to-mouth transfer efficiency for arsenic from chromated copper arsenate (CCA)-treated wood. Hand-to-mouth transfer efficiency is defined as the fraction of chemical mass that enters the mouth and remains in the mouth as a result of one hand-to-mouth contact. The value of 50% was used as the lower bound on the transfer efficiency, with 100% assigned as the upper bound and the mode of distribution set to 75%. The resulting fitted beta distribution of the hand-to-mouth transfer efficiency for arsenic had a mean value of 78% and a 75th percentile value of 84.9% per hand-to-mouth contact.

4.7.3.6 OEHHA (2008)

OEHHA (2008) published a lead exposure guideline for calculating the hand-to-mouth transfer of lead from the use of fishing tackle in recreational fishing. The guideline examined both direct and indirect hand-to-mouth activities. No data were available from the scientific literature on the amount of lead transferred from the hand to the mouth as a result of handling fishing tackle products, but data from two studies (Camann *et al*, 2000; Kissel *et al*, 1998) were found to be useful. The study by Camann *et al*. (2000) provides data on the removal of three pesticides from the hands of three adults. The study by Kissel *et al.* (1998) provides estimates on the total soil loading on the hand,

and its transfer to the mouth from particular parts of the hand (i.e., thumb; two fingers; palm) in four adults. After reviewing the data from these and other studies, OEHHA (2008) selected a value of 50% as the direct, and 25% as the indirect hand-to-mouth transfer factors for lead in fishing tackle products for adults.

U.S. EPA (2002) concluded from the data of Reed *et al.* (1999) and Zartarian *et al.* (1998) that hand-to-mouth contacts of 9 contacts/hour was a reasonable estimate for children 2 to 6 years old. Since then other published studies (Black *et al*., 2005 and Ko *et al*., 2007) reported that the hand-to-mouth value of 9 contacts/hour probably underestimates the frequency of children's hand-to-mouth activity and the frequency could be over 20 contacts/hour. OEHHA (2008) selected 9 contacts/hour as the average estimate, and 20 as the upper bound estimate of direct hand-to-mouth contact frequency for adults during fishing in contact with lead fishing tackle products.

4.7.3.7 Xue et al. (2007)

A meta-analysis was conducted by Xue and colleagues (2007) to examine hand-to-mouth frequency based on study, age groups, gender, and location (indoor vs. outdoor). Data were gathered from 9 studies (Zartarian *et al.* 1998; Reed *et al.* 1999; Leckie *et al.* 2000; Freeman *et al.* 2001; Greene, 2002; Tulve *et al.* 2002; Hore, 2003; Black *et al.* 2005; Beamer *et al.* 2008). The combined studies represent 429 subjects and more than 2,000 hours of behavior observations. To pool and analyze the data from these studies collectively, Xue *et al* (2007) contacted the authors of the 9 studies to obtain and clarify needed and missing data for the analysis.

Results of the analysis indicate that age and location are important for hand-to-mouth frequency, but not gender. As age increases, both indoor and outdoor hand-to-mouth frequencies decrease, and this behavior is higher indoors than outdoors. Average indoor hand-to-mouth frequency ranged from 6.7 to 28.0 contacts/hour, with the lowest value corresponding to the 6 years to <11 years age group and the highest value corresponding to the 3 months to <6 months group. Average outdoor hand-to-mouth frequency ranged from 2.9 to 14.5 contacts/hour, with the lowest value corresponding to the 6 years to <11 years age group and the highest value corresponding to the 6 months to <12 months group. For the 3 months to < 6 months age group, outdoor hand-to-mouth contact frequency data were not available.

The study is an important effort to provide data on hand-to-mouth contact frequency by indoor/outdoor location and age groups based on the recommendations by the U.S. EPA (2005) for assessing childhood exposures. However, it did not analyze or collect data on other mouthing behaviors such as object-to-mouth. Also, data for older children, ages 11 and above, are not included; they are likely to have very different behaviors from the younger children.

Table 4.17 Hand-to-Mouth Frequency (contacts/hour) in Children

Age Group	No. of Observations	Mean	Std Dev	P25	P50	P75	P95
		INDOORS					
3m to < 6m	23	28	21.7	8.0	23.0	48.0	65.0
6m to < 12m	119	18.9	17.4	6.6	14.0	26.4	52.0
1y to < 6y[a]	575	16.2	-	4.5	11.1	22.1	53.1
6y to < 11y	14	6.7	5.5	2.4	5.7	10.2	20.6
		OUTDOORS					
3m to < 6m	0	-	-	-	-	-	-
6m to < 12m	10	14.5	12.3	7.6	11.6	16.0	46.7
1y to < 6y[a]	133	8.7	-	1.1	5.1	11.6	32.0
6 to < 11y	15	2.9	4.3	0.1	0.5	4.7	11.9
		COMBINED					
3m to < 6m	23	28	21.7	8.0	23.0	48.0	65.0
6m to < 12m	129	18.6	-	6.7	13.8	25.6	51.6
1y to < 6y[a]	708	14.8	-	3.8	10.0	20.2	49.1
6y to < 11y	29	4.7	-	1.2	3.0	7.4	16.1

Adapted from Xue *et al.*, 2007; results are from 9 studies using Weibull distributions.

[a] Three age groups, 1y to < 2 y, 2y to <3y, and 3y to <6y, combined.

4.7.4 Extrapolation of Soil Ingestion from Hand-to-Mouth Contact

U.S. EPA (2008) in their *Child-Specific Exposure Factors Handbook* recommends 100 mg/d as the central tendency value for daily soil and dust ingestion in children 1 year to <6 years. The actual sum (soil and dust) is 110 mg/d but rounded to 100 mg/d (to one significant figure) (U.S. EPA, 2008). In the absence of data that can be used to develop soil and dust recommendations for children aged 6 to <11 years, 11 to <16 years and 16 to <21 years, U.S. EPA (2008) recommended using 100 mg/d as the central tendency value for children aged 6 to <21 years.

Using the mean weighed average value of 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (from Table 4.13 derived from the 2008 U.S. EPA document), and assuming this age group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Table 4.17), soil ingestion in other age groups can be estimated (Table 4.18).

OEHHA (2008) selects 9 and 20 as the average and upper bound estimates, respectively, of direct hand-to-mouth contact frequency for adults from the use of lead tackle in recreational fishing. Using the same extrapolation procedure above, the mean and the upper bound soil ingestion estimates were obtained. The combined soil and dust ingestion rate estimated from Xue *et al.* (2007) data for children aged 6 months to < 12 months is higher than that provided by the U.S. EPA (2008) – 133 mg/d versus 60 mg/d, respectively. We believe that the value of 133 mg/d better reflects the soil and dust ingestion rate in children aged 6 months to < 12 months because children in this age group are known to have much higher hand-to-mouth contact behavior as they explore their environment (Xue *et al.* 2007).

Table 4.18 Soil and Dust Ingestion Rates (mg/day) Extrapolated from Xue et al. (2007) Hand-to-Mouth Contact Data to Three Age Groups

Age Groups	Mean	P95
3m to < 6m	NC[a]	NC
6m to < 12m	133	370
1y to < 6y	106	352
6 to < 11y	34[b]	115[b]
Adult	64	143

[a] Not calculated as there is no hand-to-mouth contact in this group
[b] Low confidence level for this number due to low number of observations

OEHHA supports the U.S. EPA (2008) recommendations of 100 mg/day as the central tendency of the combined soil and dust ingestion rate for children aged 1 to <6 years. This number was rounded down from the actual number of 110 mg/d. Using 110 mg/day for soil and dust ingestion for the age group 1 to <6 years old (Table 4-13), and assuming this group has combined indoor and outdoor hand-to-mouth contacts of 14.8/hour (from Figure 4-17), soil and dust ingestion in other age groups are extrapolated from hand-to-mouth data (Table 4-18). The value for the 6 to <11 year old group is not used because of the low number of hand-to-mouth observations in this group. The soil ingestion values for adults and children (mg/day) estimated for the various age groups are shown in Table 4.19.

Table 4.19 Soil Ingestion Estimates for Adults and Children (mg/day)*

Age Groups (years)	Mean (mg/day)	95th percentile (mg/day)
3rd Trimester[a]	**50**	**200**
0 < 2	150	400
2<9	100	400
2<16	100	400
9<16	100	400
16<30	50	200
30>70	50	200
PICA children	5000	-
PICA adult	NR[b]	-

[a] Assumed to be the mother’s soil ingestion rate (adult age 16 <30)
[b] No recommendation
* Soil includes outdoor settled dust

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