4. SOIL INGESTION AND PICA
- 4.1 BACKGROUND
- 4.2. KEY STUDIES ON SOIL INTAKE AMONG CHILDREN
- 4.3. RELEVANT STUDIES ON SOIL INTAKE AMONG CHILDREN
- 4.4. SOIL INTAKE AMONG ADULTS
- 4.5. PREVALENCE OF PICA
- 4.6. DELIBERATE SOIL INGESTION AMONG CHILDREN
- 4.7. RECOMMENDATIONS

REFERENCES FOR CHAPTER 4

Table 4-1. Estimated Daily Soil Ingestion Based on Aluminum, Silicon, and Titanium Concentrations
Table 4-2. Calculated Soil Ingestion by Nursery School Children
Table 4-3. Calculated Soil Ingestion by Hospitalized, Bedridden Children
Table 4-4. Mean and Standard Deviation Percentage Recovery of Eight Tracer Elements
Table 4-5. Soil and Dust Ingestion Estimates for Children Aged 1-4 Years
Table 4-6. Average Daily Soil Ingestion Values Based on Aluminum, Silicon, and Titanium as Tracer Elements
Table 4-7. Geometric Mean (GM) and Standard Deviation (GSD) LTM Values for Children at Daycare Centers and Campgrounds
Table 4-8. Estimated Geometric Mean LTM Values of Children Attending Daycare Centers According to Age, Weather Category, and Sampling Period
Table 4-9. Distribution of Average (Mean) Daily Soil Ingestion Estimates Per Child for 64 Children (mg/day)
Table 4-10. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected Over 365 Days
Table 4-11. Estimates of Soil Ingestion for Children
Table 4-12. Estimated Soil Ingestion Rate Summary Statistics and Parameters for Distributions Using Binder et al. (1986) Data with Actual Fecal Weights
Table 4-13. Tukey's Multiple Comparison of Mean Log Tracer Recovery in Adults Ingesting Known Quantities of Soil
Table 4-14. Positive/Negative Error (bias) in Soil Ingestion Estimates in the Calabrese et al. (1989) Mass-balance Study: Effect on Mean Soil Ingestion Estimate (mg/day)
Table 4-15. Soil Ingestion Rates for Assessment Purposes
Table 4-16. Estimates of Soil Ingestion for Adults
Table 4-17. Adult Daily Soil Ingestion by Week and Tracer Element After Subtracting Food and Capsule Ingestion, Based on Median Amherst Soil Concentrations: Means and Medians Over Subjects (mg)

Table 4-18. Daily Soil Ingestion Estimation in a Soil-Pica Child by Tracer and by Week (mg/day)
Table 4-19. Ratios of Soil, Dust, and Residual Fecal Samples in the Pica Child
Table 4-20. Soil Intake Studies
Table 4-21. Confidence in Soil Intake Recommendation
Table 4-22. Summary of Estimates of Soil Ingestion By Children
Table 4-23. Summary of Recommended Values for Soil Ingestion

4. SOIL INGESTION AND PICA

4.1. BACKGROUND

The ingestion of soil is a potential source of human exposure to toxicants. The potential for exposure to contaminants via this source is greater for children because they are more likely to ingest more soil than adults as a result of behavioral patterns present during childhood. Inadvertent soil ingestion among children may occur through the mouthing of objects or hands. Mouthing behavior is considered to be a normal phase of childhood development. Adults may also ingest soil or dust particles that adhere to food, cigarettes, or their hands. Deliberate soil ingestion is defined as pica and is considered to be relatively uncommon. Because normal, inadvertent soil ingestion is more prevalent and data for individuals with pica behavior are limited, this section focuses primarily on normal soil ingestion that occurs as a result of mouthing or unintentional hand-to-mouth activity.

Several studies have been conducted to estimate the amount of soil ingested by children. Most of the early studies attempted to estimate the amount of soil ingested by measuring the amount of dirt present on children's hands and making generalizations based on behavior. More recently, soil intake studies have been conducted using a methodology that measures trace elements in feces and soil that are believed to be poorly absorbed in the gut. These measurements are used to estimate the amount of soil ingested over a specified time period. The available studies on soil intake are summarized in the following sections. Studies on soil intake among children have been classified as either key studies or relevant studies based on their applicability to exposure assessment needs. Recommended intake rates are based on the results of key studies, but relevant studies are also presented to provide the reader with added perspective on the current state-of-knowledge pertaining to soil intake. Information on soil ingestion among adults is presented based on available data from a limited number of studies. This is an area where more data and more research are needed. Relevant information on the prevalence of pica and intake among individuals exhibiting pica behavior is also presented.

4.2. KEY STUDIES ON SOIL INTAKE AMONG CHILDREN

Binder et al. (1986) - Estimating Soil Ingestion: Use of Tracer Elements in Estimating the Amount of Soil Ingested by Young Children - Binder et al. (1986) studied the ingestion of soil among children 1 to 3 years of age who wore diapers using a tracer technique modified from a method previously used to measure soil ingestion among grazing animals. 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. Soiled diapers were collected over a 3-day period from 65 children (42 males and 23 females), and composited samples of

soil were obtained from the children's yards. Both excreta and soil samples were analyzed for aluminum, silicon, and titanium. These elements were found in soil, but were thought to be poorly absorbed in the gut and to have been present in the diet only in limited quantities. This made them useful tracers for estimating soil intake. Excreta measurements were obtained for 59 of the children. Soil ingestion by each child was estimated based on each of the three tracer elements using a standard assumed fecal dry weight of 15 g/day, and the following equation:

$$T_{i,e} = \frac{f_{i,e} \times F_i}{S_{i,e}} \qquad \text{(Eqn. 4-1)}$$

where:

$T_{i,e}$ = estimated soil ingestion for child i based on element e (g/day);
$f_{i,e}$ = concentration of element e in fecal sample of child i (mg/g);
F_i = fecal dry weight (g/day); and
$S_{i,e}$ = concentration of element e in child i's yard soil (mg/g).

The analysis conducted by Binder et al. (1986) assumed that: (1) the tracer elements were neither lost nor introduced during sample processing; (2) the soil ingested by children originates primarily from their own yards; and (3) that absorption of the tracer elements by children occurred in only small amounts. The study did not distinguish between ingestion of soil and housedust nor did it account for the presence of the tracer elements in ingested foods or medicines.

The arithmetic mean quantity of soil ingested by the children in the Binder et al. (1986) study was estimated to be 181 mg/day (range 25 to 1,324) based on the aluminum tracer; 184 mg/day (range 31 to 799) based on the silicon tracer; and 1,834 mg/day (range 4 to 17,076) based on the titanium tracer (Table 4-1). The overall mean soil ingestion estimate based on the minimum of the three individual tracer estimates for each child was 108 mg/day (range 4 to 708). The 95th percentile values for aluminum, silicon, and titanium were 584 mg/day, 578 mg/day, and 9,590 mg/day, respectively. The 95th percentile value based on the minimum of the three individual tracer estimates for each child was 386 mg/day.

The authors were not able to explain the difference between the results for titanium and for the other two elements, but speculated that unrecognized sources of titanium in the diet or in the laboratory processing of stool samples may have accounted for the increased levels. The frequency distribution graph of soil ingestion estimates based on titanium shows that a group of 21 children had particularly high titanium values (i.e.,

>1,000 mg/day). The remainder of the children showed titanium ingestion estimates at lower levels, with a distribution more comparable to that of the other elements.

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, the children studied may not be representative of the U.S. population and the study did not account for tracers ingested via foods or medicines. Also, the use of an assumed fecal weight instead of actual fecal weights may have biased the results of this study. Finally, because of the short-term nature of the survey, soil intake estimates may not be entirely representative of long-term behavior, especially at the upper-end of the distribution of intake.

Clausing et al. (1987) - A Method for Estimating Soil Ingestion by Children - Clausing et al. (1987) conducted a soil ingestion study with Dutch children using a tracer element methodology similar to that of Binder et al. (1986). 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, Clausing et al. (1987) estimated soil ingestion for each tracer. Clausing et al. (1987) also collected eight daily fecal samples from six hospitalized, bedridden children. These children served as a control group, representing children who had very limited access to soil.

The average quantity of soil ingested by the school children in this study was as follows: 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 (Table 4-2). As in the Binder et al. (1986) study, a fraction of the children (6/19) showed titanium values well above 1,000 mg/day, with most of the remaining children showing substantially lower values. Based on the Limiting Tracer Method (LTM), mean soil intake was estimated to be 105 mg/day with a population standard deviation of 67 mg/day (range 23 to 362 mg/day). Use of the LTM assumed that "the maximum amount of soil ingested corresponded with the lowest estimate from the three tracers" (Clausing et al., 1987). Geometric mean soil intake was estimated to be 90 mg/day. This assumes that the maximum amount of soil ingested cannot be higher than the lowest estimate for the individual tracers.

Mean soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum (Table 4-3). For titanium, three of the 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. Using the LTM method, 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. The data on hospitalized children suggest a major nonsoil source of titanium for some children, and may suggest a background nonsoil source of aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered. AIR measurements were not reported for the hospitalized children. Assuming that the tracer-based soil ingestion rates observed in hospitalized children actually represent background tracer intake from dietary and other nonsoil sources, mean soil ingestion by nursery school children was estimated to be 56 mg/day, based on the LTM (i.e., 105 mg/day for nursery school children minus 49 mg/day for hospitalized children) (Clausing et al. 1987).

The advantages of this study are that Clausing et al. (1987) evaluated soil ingestion among two populations of children that had differences in access to soil, and corrected soil intake rates based on background estimates derived from the hospitalized group. However, a smaller number of children were used in this study than in the Binder et al. (1986) study and these children may not be representative of the U.S. population. Tracer elements in foods or medicines were not evaluated. Also, intake rates derived from this study may not be representative of soil intake over the long-term because of the short-term nature of the study. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Calabrese et al. (1989) - How Much Soil do Young Children Ingest: An Epidemiologic Study - Calabrese et al. (1989) studied soil ingestion among children using the basic tracer design developed by Binder et al. (1986). However, in contrast to the Binder et al. (1986) study, eight tracer elements (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) were analyzed instead of only three (i.e., aluminum, silicon, and titanium). A total of 64 children between the ages of 1 and 4 years old were included in the study. These children were all selected from the greater Amherst, Massachusetts area and were predominantly from two-parent households where the parents were highly educated. The Calabrese et al. (1989) study was conducted over eight days during a two week period and included the use of a mass-balance methodology in which duplicate samples of food, medicines, vitamins, and others were collected and analyzed on a daily basis, in addition to soil and dust samples collected from the child's home and play area. Fecal and urine samples were also collected and analyzed for tracer elements. Toothpaste, low in tracer content, was provided to all participants.

In order to validate the mass-balance methodology used to estimate soil ingestion rates among children and to determine which tracer elements provided the most reliable data on soil ingestion, known amounts of soil (i.e., 300 mg over three days and 1,500 mg

over three days) containing eight tracers were administered to six adult volunteers (i.e., three males and three females). Soil samples and feces samples from these adults and duplicate food samples were analyzed for tracer elements to calculate recovery rates of tracer elements in soil. Based on the adult validation study, Calabrese et al. (1989) confirmed that the tracer methodology could adequately detect tracer elements in feces at levels expected to correspond with soil intake rates in children. Calabrese et al. (1989) also found that aluminum, silicon, and yttrium were the most reliable of the eight tracer elements analyzed. The standard deviation of recovery of these three tracers was the lowest and the percentage of recovery was closest to 100 percent (Calabrese, et al., 1989). The recovery of these three tracers ranged from 120 to 153 percent when 300 mg of soil had been ingested over a three-day period and from 88 to 94 percent when 1,500 mg soil had been ingested over a three-day period (Table 4-4).

Using the three most reliable tracer elements, the mean soil intake rate for children, adjusted to account for the amount of tracer found in food and medicines, was estimated to be 153 mg/day based on aluminum, 154 mg/day based on silicon, and 85 mg/day based on yttrium (Table 4-5). Median intake rates were somewhat lower (29 mg/day for aluminum, 40 mg/day for silicon, and 9 mg/day for yttrium). Upper-percentile (i.e., 95th) values were 223 mg/day for aluminum, 276 mg/day for silicon, and 106 mg/day for yttrium. Similar results were observed when soil and dust ingestion was combined (Table 4-5). Intake of soil and dust was estimated using a weighted average of tracer concentration in dust composite samples and in soil composite samples based on the timechildren spent at home and away from home, and indoors and outdoors. Calabrese et al. (1989) suggested that the use of titanium as a tracer in earlier studies that lacked food ingestion data may have significantly overestimated soil intake because of the high levels of titanium in food. Using the median values of aluminum and silicon, Calabrese et al. (1989) estimated the quantity of soil ingested daily to be 29 mg/day and 40 mg/day, respectively. It should be noted that soil ingestion for one child in the study ranged from approximately 10 to 14 grams/day during the second week of observation. Average soil ingestion for this child was 5 to 7 mg/day, based on the entire study period.

The advantages of this study are that intake rates were corrected for tracer concentrations in foods and medicines and that the methodology was validated using adults. Also, intake was observed over a longer time period in this study than in earlier studies and the number of tracers used was larger than for other studies. A relatively large population was studied, but they may not be entirely representative of the U.S. population because they were selected from a single location.

Davis et al. (1990) - Quantitative Estimates of Soil Ingestion in Normal Children Between the ages of 2 and 7 years: Population-Based Estimates Using Aluminum, Silicon, and Titanium as Soil Tracer Elements - Davis et al. (1990) also used a mass-

balance/tracer technique to estimate soil ingestion among children. In this study, 104 children between the ages of 2 and 7 years were randomly selected from a three-city area in southeastern Washington State. The study was conducted over a seven day period, primarily during the summer. Daily soil ingestion was evaluated by collecting and analyzing soil and house dust samples, 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 amount of soil ingested on a daily basis was estimated using the following equation:

$$S_{i,e} = \frac{(DW_f - DW_p) \times (E_f - 2E_u) - (DW_{fd} \times E_{fd})}{E_{soil}} \qquad \text{(Eqn. 4-2)}$$

where:

$S_{i,e}$ = soil ingested for child i based on tracer e (g);
DW_f = feces dry weight (g);
DW_p = feces dry weight on toilet paper (g);
E_f = tracer amount in feces (μg/g);
E_u = tracer amount in urine (μg/g);
DW_{fd} = food dry weight (g);
E_{fd} = tracer amount in food (μg/g); and
E_{soil} = tracer concentration in soil (μg/g).

The soil intake rates were corrected by adding the amount of tracer in vitamins and medications to the amount of tracer in food, and adjusting the food quantities, feces dry weights, and tracer concentrations in urine to account for missing samples.

Soil ingestion rates were highly variable, especially those based on titanium. Mean daily soil ingestion estimates were 38.9 mg/day for aluminum, 82.4 mg/day for silicon and 245.5 mg/day for titanium (Table 4-6). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. Davis et al. (1990) also evaluated the extent to which differences in tracer concentrations in house dust and yard soil impacted estimated soil ingestion rates. The value used in the denominator of the mass balance equation was recalculated to represent a weighted average of the tracer concentration in yard soil and house dust based on the proportion of time the child spent indoors and outdoors. The adjusted mean soil/dust intake rates were 64.5 mg/day for aluminum, 160.0 mg/day for silicon, and 268.4 mg/day for titanium. Adjusted median soil/dust intake rates were: 51.8 mg/day for aluminum, 112.4 mg/day for silicon, and 116.6 mg/day for titanium. Davis et al. (1990) also observed that the following demographic characteristics were associated with high soil intake rates: male sex, non-white racial group, 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.

The advantages of the Davis et al. (1990) study are that soil intake rates were corrected based on the tracer content of foods and medicines and that a relatively large number of children were sampled. Also, demographic and behavioral information was collected for the survey group. However, 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) patterns of intake.

Van Wïjnen et al. (1990) - Estimated Soil Ingestion by Children - In a study by Van Wïjnen et al. (1990), soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using a tracer element methodology similar to that used by Clausing et al. (1987). Van Wïjnen et al. (1990) measured three tracers (i.e., titanium, aluminum, and AIR) in soil and feces and estimated soil ingestion based on the LTM. An average daily feces weight of 15 g dry weight was assumed. A total of 292 children attending daycare centers were sampled during the first of two sampling periods and 187 children were sampled in the second sampling period; 162 of these children were sampled during both periods (i.e., at the beginning and near the end of the summer of 1986). A total of 78 children were sampled at campgrounds, and 15 hospitalized children were sampled. The mean 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. Van Wïjnen et al. (1990) also reported geometric mean LTM values because soil intake rates were found to be skewed and the log transformed data were approximately normally distributed. Geometric mean LTM values were estimated to be 111 mg/day for children in daycare centers, 174 mg/day for children vacationing at campgrounds (Table 4-7) and 74 mg/day for hospitalized children (70-120 mg/day based on the 95 percent confidence limits of the mean). 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 (i.e., <2 days/week precipitation) than when the weather was bad (i.e., >4 days/week precipitation (Table 4-8). Van Wïjnen et al. (1990) suggest that the mean LTM value for hospitalized infants represents background intake of tracers and should be used to correct the soil intake rates based on LTM values for other sampling groups. Using mean values, corrected soil intake rates were 69 mg/day (162 mg/day minus 93 mg/day) for daycare children and 120 mg/day (213 mg/day minus 93 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 advantage of this study is that soil intake was estimated for three different populations of children; one expected to have high intake, one expected to have "typical" intake, and one expected to have low or background-level intake. Van Wïjnen et al. (1990) used the background tracer measurements to correct soil intake rates for the other two populations. Tracer concentrations in food and medicine were not evaluated. Also, the population of children studied was relatively large, but may not be representative of the U.S. population. This study was conducted over a relatively short time period. Thus, 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 which would be the preferred way of reporting. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Stanek and Calabrese (1995a) - Daily Estimates of Soil Ingestion in Children - Stanek and Calabrese (1995a) presented a methodology which links the physical passage of food and fecal samples to construct daily soil ingestion estimates from daily food and fecal trace-element concentrations. Soil ingestion data for children obtained from the Amherst study (Calabrese et al., 1989) were reanalyzed by Stanek and Calabrese (1995a). In the Amherst study, soil ingestion measurements were made over a period of 2 weeks for a non-random sample of sixty-four children (ages of 1-4 years old) living adjacent to an academic area in western Massachusetts. During each week, duplicate food samples were collected for 3 consecutive days and fecal samples were collected for 4 consecutive days for each subject. The total amount of each of eight trace elements present in the food and fecal samples were measured. The eight trace elements are aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium. The authors expressed the amount of trace element in food input or fecal output as a "soil equivalent," which was defined as the amount of the element in average daily food intake (or average daily fecal output) divided by the concentration of the element in soil. A lag period of 28 hours between food intake and fecal output was assumed for all respondents. Day 1 for the food sample corresponded to the 24 hour period from midnight on Sunday to midnight on Monday of a study week; day 1 of the fecal sample corresponded to the 24 hour period from noon on Monday to noon on Tuesday (Stanek and Calabrese, 1995a). Based on these definitions, the food soil equivalent was subtracted from the fecal soil equivalent to obtain an estimate of soil ingestion for a trace element. A daily “overall” ingestion estimate was constructed for each child as the median of trace element values remaining after tracers falling outside of a defined range around the overall median were excluded.

Additionally, estimates of the distribution of soil ingestion projected over a period of 365 days were derived by fitting log-normal distributions to the "overall" daily soil ingestion estimates.

Table 4-9 presents the estimates of mean daily soil ingestion intake per child (mg/day) for the 64 study participants. (The authors also presented estimates of the median values of daily intake for each child. For most risk assessment purposes the child mean values, which are proportional to the cumulative soil intake by the child, are needed instead of the median values.) The approach adopted in this paper led to changes in ingestion estimates from those presented in Calabrese et al. (1989). Specifically, among elements that may be more useful for estimation of ingestion, the mean estimates decreased for Al (153 mg/d to 122 mg/d) and Si (154 mg/d to 139 mg/d), but increased for Ti (218 mg/d to 271 mg/d) and Y (85 mg/d to 165 mg/d). The "overall" mean estimate from this reanalysis was 179 mg/d. Table 4-9 presents the empirical distribution of the the "overall" mean daily soil ingestion estimates for the 8-day study period (not based on lognormal modeling). The estimated intake based on the "overall" estimates is 45 mg/day or less for 50 percent of the children and 208 mg/day or less for 95 percent of the children. The upper percentile values for most of the individual trace elements are somewhat higher. Next, estimates of the respondents soil intake averaged over a period of 365 days were presented based upon the lognormal models fit to the daily ingestion estimates (Table 4-10). The estimated median value of the 64 respondents' daily soil ingestion averaged over a year is 75 mg/day, while the 95th percentile is 1,751 mg/day.

A strength of this study is that it attempts to make full use of the collected data through estimation of daily ingestion rates for children. The data are then screened to remove less consistent tracer estimates and the remaining values are aggregated. Individual daily estimates of ingestion will be subject to larger errors than are weekly average values, particularly since the assumption of a constant lag time between food intake and fecal output may be not be correct for many subject days. The aggregation approach used to arrive at the "overall" ingestion estimates rests on the assumption that the mean ingestion estimates across acceptable tracers provides the most reliable ingestion estimates. The validity of this assumption depends on the particular set of tracers used in the study, and is not fully assessed.

In developing the 365 day soil ingestion estimates, data that were obtained over a short period of time (as is the case with all available soil ingestion studies) were extrapolated over a year. The 2-week study period may not reflect variability in tracer element ingestion over a year. While Stanek and Calabrese (1995a) attempt to address this through lognormal modeling of the long term intake, new uncertainties are introduced through the parametric modeling of the limited subject day data. Also, the sample population size of the original study was small and site limited, and, therefore, is not

representative of the U.S. population. Study mean estimates of soil ingestion, such as the study mean estimates presented in Table 4-9, are substantially more reliable than any available distributional estimates.

Stanek and Calabrese (1995b) - Soil Ingestion Estimates for Use in Site Evaluations Based on the Best Tracer Method - Stanek and Calabrese (1995b) recalculated ingestion rates that were estimated in three previous mass-balance studies (Calabrese et al., 1989 and Davis et al., 1990 for children's soil ingestion, and Calabrese et al., 1990 for adult soil ingestion) using the Best Tracer Method (BTM). This method allows for the selection of the most recoverable tracer for a particular subject or group of subjects. The selection process involves ordering trace elements for each subject based on food/soil (F/S) ratios. These ratios are estimated by dividing the total amount of the tracer in food by the tracer concentration in soil. The F/S ratio is small when the tracer concentration in food is almost zero when compared to the tracer concentration in soil. A small F/S ratio is desirable because it lessens the impact of transit time error (the error that occurs when fecal output does not reflect food ingestion, due to fluctuation in gastrointestinal transit time) in the soil ingestion calculation. Because the recoverability of tracers can vary within any group of individuals, the BTM uses a ranking scheme of F/S ratios to determine the best tracers for use in the ingestion rate calculation. To reduce biases that may occur as a result of sources of fecal tracers other than food or soil, the median of soil ingestion estimates based on the four lowest F/S ratios was used to represent soil ingestion among individuals.

For adults, Stanek and Calabrese (1995b) used data for 8 tracers from the Calabrese et al. (1990) study to estimate soil ingestion by the BTM. The lowest F/S ratios were Zr and Al and the element with the highest F/S ratio was Mn. For soil ingestion estimates based on the median of the lowest four F/S ratios, the tracers contributing most often to the soil ingestion estimates were Al, Si, Ti, Y, V, and Zr. Using the median of the soil ingestion rates based on the best four tracer elements, the average adult soil ingestion rate was estimated to be 64 mg/day with a median of 87 mg/day. The 90th percentile soil ingestion estimate was 142 mg/day. These estimates are based on 18 subject weeks for the six adult volunteers described in Calabrese et al. (1990).

For children, Stanek and Calabrese (1995b) used data on 8 tracers from Calabrese et al., 1989 and data on 3 tracers from Davis et al. (1990) to estimate soil ingestion rates. The median of the soil ingestion estimates from the lowest four F/S ratios from the Calabrese et al. (1989) study most often included Al, Si, Ti, Y, and Zr. Based on the median of soil ingestion estimates from the best four tracers, the mean soil ingestion rate was 132 mg/day and the median was 33 mg/day. The 95th percentile value was 154 mg/day. These estimates are based on data for 128 subject weeks for the 64 children in the Calabrese et al. (1989) study. 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. These data are based on the three tracers (i.e., Al, Si, and Ti) from the Davis et al. (1990) study. When the Calabrese et al. (1989) and Davis et al. (1990) studies were combined, soil ingestion was estimated to be 113 mg/day (mean); 37 mg/day (median); and 217 mg/day (95th percentile), using the BTM.

This study provides a reevaluation of previous studies. Its advantages are that it combines data from 2 studies for children, one from California and one from Massachusetts, which increases the number of observations. It also corrects for biases associated with the differences in tracer metabolism. The limitations associated with the data used in this study are the same as the limitations described in the summaries of the Calabrese et al. (1989), Davis et al. (1990) and Calabrese et al. (1990) studies.

4.3. RELEVANT STUDIES ON SOIL INTAKE AMONG CHILDREN

Lepow et al. (1975) - Investigations Into Sources of Lead in the Environment of Urban Children - Lepow et al. (1975) used data from a previous study (Lepow et al., 1974) to estimate daily soil ingestion rates of children. Lepow et al. (1974) estimated ingestion of airborne lead fallout among urban children by: (1) analyzing surface dirt and dust samples from locations where children played; (2) measuring hand dirt by applying preweighed adhesive labels to the hands and weighing the amount of dirt that was removed; and (3) observing "mouthing" behavior over 3 to 6 hours of normal play. Twenty-two children from an urban area of Connecticut were included in the study. Lepow et al. (1975) used data from the 1974 study and found that the mean weight of soil/dust on the hands was 11 mg. Assuming that a child would put fingers or other "dirty" objects into his mouth about 10 times a day ingesting 11 mg of dirt each time, Lepow et al. (1975) estimated that the daily soil ingestion rate would be about 100 mg/day. According to Lepow et al. (1975), the amount of hand dirt measured with this technique is probably an underestimate because dirt trapped in skin folds and creases was probably not removed by the adhesive label. Consequently, mean soil ingestion rates may be somewhat higher than the values estimated in this study.

Day et al. (1975) - Lead in Urban Street Dust - Day et al. (1975) evaluated the contribution of incidental ingestion of lead-contaminated street dust and soil to children's total daily intake of lead by measuring the amount of lead in street dust and soil and estimating the amount of dirt ingested by children. The amount of soil that might be ingested was estimated by measuring the amount of dirt that was transferred to a "sticky sweet" during 30 minutes of play and assuming that a child might eat from 2 to 20 such sweets per day. Based on "a small number of direct measurements," Day et al. (1975) found that 5 to 50 mg of dirt from a child's hands may be transferred to a "sticky sweet" during 30 minutes of "normal playground activity. Assuming that all of the dirt is ingested

with the 2 to 20 "sticky sweets," Day et al. (1975) estimated that intake of soil among children could range from 10 to 1000 mg/day.

Duggan and Williams (1977) - Lead in Dust in City Streets - Duggan and Williams (1977) assessed the risks associated with lead in street dust by analyzing street dust from areas in and around London for lead, and estimating the amount of hand dirt that a child might ingest. Duggan and Williams (1977) estimated the amount of dust that would be retained on the forefinger and thumb by removing a small amount of dust from a weighed amount, rubbing the forefinger and thumb together, and reweighing to determine the amount retained on the finger and thumb. The results of "a number of tests with several different people" indicated that the mean amount of dust retained on the finger and thumb was approximately 4 mg with a range of 2 to 7 mg (Duggan and Williams, 1977). Assuming that a child would suck his/her finger or thumb 10 times a day and that all of the dirt is removed each time and replaced with new dirt prior to subsequent mouthing behavior, Duggan and Williams (1977) estimated that 20 mg of dust would be ingested per day.

Hawley et al. (1985) - Assessment of Health Risk from Exposure to Contaminated Soil - Using existing literature, Hawley (1985) developed scenarios for estimating exposure of young children, older children, and adults to contaminated soil. Annual soil ingestion rates were estimated based on assumed intake rates of soil and housedust for indoor and outdoor activities and assumptions about the duration and frequency of the activities. These soil ingestion rates were based on the assumption that the contaminated area is in a region having a winter season. Housedust was assumed to be comprised of 80 percent soil.

Outdoor exposure to contaminated soil among young children (i.e., 2.5 years old) was assumed to occur 5 days per week during only 6 months of the year (i.e., mid-April through mid-October). Children were assumed to ingest 250 mg soil/day while playing outdoors based on data presented in Lepow et al. (1974; 1975) and Roels et al. (1980). Indoor exposures among this population were based on the assumption that young children ingest 100 mg of housedust per day while spending all of their time indoors during the winter months, and 50 mg of housedust per day during the warmer months when only a portion of their time is spent indoors. Based on these assumptions, Hawley (1985) estimated that the annual average soil intake rate for young children is 150 mg/day (Table 4-11). Older children (i.e., 6 year olds) were assumed to ingest 50 mg of soil per day from an area equal to the area of the fingers on one hand while playing outdoors. This assumption was based on data from Lepow et al. (1975). Outdoor activities were assumed to occur each day over 5 months of the year (i.e., during May through October). These children were also assumed to ingest 3 mg/day of housedust from the indoor surfaces of the hands during

indoor activities occurring over the entire year. Using these data, Hawley (1985) estimated the annual average soil intake rate for older children to be 23.4 mg/day (Table 4-11).

Thompson and Burmaster (1991) - Parametric Distributions for Soil Ingestion by Children - Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the data collected by Binder et al. (1986). In the original Binder et al. (1986) study, an assumed fecal weight of 15 g/day was used. Thompson and Burmaster reestimated 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). Table 4-12 presents the distribution of estimated soil ingestion rates calculated by Thompson and Burmaster (1991) based on the three tracers elements (i.e., aluminum, silicon, and titanium), and on the arithmetic average of soil ingestion based on aluminum and silicon. 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.

Thompson and Burmaster (1991) tested the hypothesis that soil ingestion rates based on the adjusted Binder et al. (1986) data for aluminum, silicon and the average of these two tracers were lognormally distributed. The distribution of soil intake based on titanium was not tested for lognormality because titanium may be present in food in high concentrations and the Binder et al. (1986) study did not correct for food sources of titanium (Thompson and Burmaster, 1991). Although visual inspection of the distributions for aluminum, silicon, and the average of these tracers all indicated that they may be lognormally distributed, statistical tests indicated that only silicon and the average of the silicon and aluminum tracers were lognormally distributed. Soil intake rates based on aluminum were not lognormally distributed. Table 4-12 also presents the lognormal distribution parameters and underlying normal distribution parameters (i.e., the natural logarithms of the data) for aluminum, silicon, and the average of these two tracers. According to the authors, "the parameters estimated from the underlying normal distribution are much more reliable and robust" (Thompson and Burmaster, 1991).

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. In addition, the study did not generate "new" data. Instead, it provided a reanalysis of previously-reported data using actual fecal weights. No corrections were made for tracer intake from food or medicine and the results may not be

representative of long-term intake rates because the data were derived from a short-term study.

Sedman and Mahmood (1994) - Soil Ingestion by Children and Adults Reconsidered Using the Results of Recent Tracer Studies - Sedman and Mahmood (1994) used the results of two recent children's (Calabrese et al. 1989; Davis et al. 1990) tracer studies to determine estimates of average daily soil ingestion in young children and for over a lifetime. In the two studies, the intake and excretion of a variety of tracers were monitored, and concentrations of tracers in soil adjacent to the children's dwellings were determined (Sedman and Mahmood, 1994). From a mass balance approach, estimates of soil ingestion in these children were determined by dividing the excess tracer intake (i.e., 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. Sedman and Mahmood (1994) adjusted the mean estimates of soil ingestion in children for each tracer (Y) from both studies to reflect that of a 2-year old child using the following equation:

$$Y_i \; ' \; x \; e^{(\&0.112(yr)} \qquad \text{(Eqn. 4-3)}$$

where:

Y_i = adjusted mean soil ingestion (mg/day)
x = a constant
yr = average age (2 years)

In addition to the study in young children, a study (Calabrese et al., 1989) in adults was conducted to evaluate the tracer methodology. In the adult studies, percent recoveries of tracers were determined in six adults who ingested known quantities of tracers in 1.5 or 0.3 grams of soil. The distribution of tracer recoveries from adults was evaluated using data analysis techniques involving visualization and exploratory data analysis (Sedman and Mahmood, 1994). From the results obtained in these studies, the distribution of tracer recoveries from adults were determined. In addition, an analysis of variance (ANOVA) and Tukey's multiple comparison methodologies were employed to identify differences in the recoveries of the various tracers (Sedman and Mahmood, 1994).

From the adult studies, the ANOVA of the natural logarithm of the recoveries of tracers from 0.3 or 1.5 g of ingested soil showed a significant difference ($\propto$ =0.05) among the estimates of recovery of the tracers regardless of whether the recoveries were combined or analyzed separately (Sedman and Mahmood, 1994). Sedman and Mahmood (1994) also reported that barium, manganese, and zirconium yielded significantly different estimates of soil ingestion than the other tracers (aluminum, silicon, yttrium, titanium, and

vanadium). Table 4-13 presents the Tukey's multiple comparison of mean log tracer recovery in adults ingesting known quantities of soil.

The average ages of children in the two recent studies were 2.4 years in Calabrese, et al. (1989) and 4.7 years in Davis et al. (1990). 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 (Sedman and Mahmood, 1994). From the adjusted soil ingestion estimates, based on a normal distribution of means, the mean estimate for a 2-year old child was 195 mg/day and the overall mean of soil ingestion and the standard error of the mean was 53 mg/day (Sedman and Mahmood, 1994). Based on uncertainties associated with the method employed, Sedman and Mahmood (1994) 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, an average daily soil ingestion over a lifetime was estimated to be 70 mg/day. The lifetime estimates were derived using the equation presented above that describes changes in soil ingestion with age (Sedman and Mahmood, 1994).

AIHC Exposure Factors Sourcebook (1994) - The Exposure Factors Sourcebook (AIHC, 1994) uses data from the Calabrese et al. (1990) study to derive soil ingestion rates using zirconium as the tracer. More recent papers indicate that zirconium is not a good tracer. Therefore, the values recommended in the AIHC Sourcebook are not appropriate. Furthermore, because individuals were only studied for a short period of time, deriving a distribution of usual intake is not possible and is inappropriate.

Calabrese and Stanek (1995) - Resolving Intertracer Inconsistencies in Soil Ingestion Estimation - Calabrese and Stanek (1995) explored sources and magnitude of positive and negative errors in soil ingestion estimates for children on a subject-week and trace element basis. Calabrese and Stanek (1995) identified possible sources of positive errors to be the following:

- Ingestion of high levels of tracers before the study starts and low ingestion during study period may result in over estimation of soil ingestion; and

- Ingestion of element tracers from a non-food or non-soil source during the study period.

Possible sources of negative bias identified by Calabrese and Stanek (1995) are the following:

- Ingestion of tracers in food, but the tracers are not captured in the fecal sample either due to slow lag time or not having a fecal sample available on the final study day; and

- Sample measurement errors which result in diminished detection of fecal tracers, but not in soil tracer levels.

The authors developed an approach which attempted to reduce the magnitude of error in the individual trace element ingestion estimates. Results from a previous study conducted by Calabrese et al. (1989) were used to quantify these errors based on the following criteria: (1) a lag period of 28 hours was assumed for the passage of tracers ingested in food to the feces (this value was applied to all subject-day estimates); (2) daily soil ingestion rate was estimated for each tracer for each 24-hr day a fecal sample was obtained; (3) the median tracer-based soil ingestion rate for each subject-day was determined. Also, upper and lower bound estimates were determined based on criteria formed using an assumption of the magnitude of the relative standard deviation (RSD) presented in another study conducted by Stanek and Calabrese (1995a). 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 magnitude of positive or negative error for a specific tracer per day was derived by determining the difference between the value for the tracer and the median value; (4) negative errors due to missing fecal samples at the end of the study period were also determined (Calabrese and Stanek, 1995).

Table 4-14 presents the estimated magnitude of positive and negative error for six tracer elements in the children's study (i.e., conducted by Calabrese et al., 1989). 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 (Table 4-14). 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 (Table 4-14). Calabrese and Stanek (1995) concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion.

This report is valuable in providing additional understanding of the nature of potential errors in trace element specific estimates of soil ingestion. However, the operational definition used for estimating the error in a trace element estimate was the observed difference of that tracer from a median tracer value. Specific identification of sources of

error, or direct evidence that individual tracers were indeed in error was not developed. Corrections to individual tracer means were then made according to how different values for that tracer were from the median values. 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 and need not be correct. The approach used for the estimation of daily tracer intake is the same as in Stanek and Calabrese (1995a), and some limitations of that approach are mentioned in the review of that study.

Sheppard (1995) - Parameter Values to Model the Soil Ingestion Pathway - Sheppard (1995) summarized the available literature on soil ingestion to estimate the amount of soil ingestion in humans for the purposes of risk assessment. Sheppard (1995) categorized the available soil ingestion studies into two general approaches: (1) those that measured the soil intake rate with the use of tracers in the soil, and (2) those that estimated soil ingestion based on activity (e.g., hand-to-mouth) and exposure duration. Sheppard (1995) provided estimates of soil intake based on previously published tracer studies. The data from these studies were assumed to be lognormally distributed due to the broad range, the concept that soil ingestion is never zero, and the possibility of very high values. In order to account for skewness in the data, geometric means rather than arithmetic means, were calculated by age, excluding pica and geophagy values. The geometric mean for soil ingestion rate for children under six was estimated to be 100 mg/day. For children over six and adults, the geometric mean intake rate was estimated to be 20 mg/day. Sheppard (1995) also provided soil ingestion estimates for indoor and outdoor activities based on data from Hawley (1985) and assumptions regarding duration of exposure (Table 4-15).

Sheppard's (1995) estimates, based on activity and exposure duration, are quite similar to the mean values from intake rate estimates described in previous sections. The advantages of this study are that the model can be used to calculate the ingestion rate from non-food sources with variability in exposure ingestion rates and exposure durations. The limitation of this study is that it does not introduce new data; previous data are re-evaluated. In addition, because the model is based on previous data, the same advantages and limitations of those studies apply.

4.4. SOIL INTAKE AMONG ADULTS

Hawley 1985 - Assessment of Health Risk from Exposure to Contaminated Soil - Information on soil ingestion among adults is very limited. Hawley (1985) estimated soil ingestion among adults based on assumptions regarding activity patterns and corresponding ingestion amounts. Hawley (1985) assumed that adults ingest outdoor soil at a rate of 480 mg/day while engaged in yardwork or other physical activity. These outdoor exposures were assumed to occur 2 days/week during 5 months of the year (i.e.,

May through October). The ingestion estimate was based on the assumption that a 50 μm/thick layer of soil is ingested from the inside surfaces of the thumb and fingers of one hand. Ingestion of indoor housedust was assumed to occur from typical living space activities such as eating and smoking, and work in attics or other uncleaned areas of the house. Hawley (1985) assumed that adults ingest an average of 0.56 mg housedust/day during typical living space activities and 110 mg housedust/day while working in attics. Attic work was assumed to occur 12 days/year. Hawley (1985) also assumed that soil comprises 80 percent of household dust. Based on these assumptions about soil intake and the frequency of indoor and outdoor activities, Hawley (1985) estimated the annual average soil intake rate for adults to be 60.5 mg/day (Table 4-16).

The soil intake value estimated by Hawley (1985) is consistent with adult soil intake rates suggested by other researchers. Calabrese et al. (1987) suggested that soil intake among adults ranges from 1 to 100 mg/day. According to Calabrese et al. (1987), these values "are conjectural and based on fractional estimates" of earlier Center for Disease Control (CDC) estimates. In an evaluation of the scientific literature concerning soil ingestion rates for children and adults (Krablin, 1989), Arco Coal Company suggested that 10 mg/day may be an appropriate value for adult soil ingestion. This value is based on "extrapolation from urine arsenic epidemiological studies and information on mouthing behavior and time activity patterns" (Krablin, 1989).

Calabrese et al. (1990) - Preliminary Adult Soil Ingestion Estimates: Results of a Pilot Study- Calabrese et al. (1990) studied six adults to evaluate the extent to which they ingest soil. This adult study was originally part of the children soil ingestion study conducted by Calabrese and was used to validate part of the analytical methodology used in the children study. The participants were six healthy adults, three males and three females, 25-41 years old. Each volunteer ingested one empty gelatin capsule at breakfast and one at dinner Monday, Tuesday, and Wednesday during the first week of the study. During the second week, they ingested 50 mg of sterilized soil within a gelatin capsule at breakfast and at dinner (a total of 100 mg of sterilized soil per day) for 3 days. For the third week, the participants ingested 250 mg of sterilized soil in a gelatin capsule at breakfast and at dinner (a total of 500 mg of soil per day) during the three days. Duplicate meal samples (food and beverage) were collected from the six adults. The sample included all foods ingested from breakfast Monday, through the evening meal Wednesday during each of the 3 weeks. In addition, all medications and vitamins ingested by the adults were collected. Total excretory output were collected from Monday noon through Friday midnight over 3 consecutive weeks. Table 4-17 provides the mean and median values of soil ingestion for each element by week. Data obtained from the first week, when empty gelatin capsules were ingested, may be used to derive an estimate of soil intake by adults. The mean intake rates for the eight tracers are: Al, 110 mg; Ba, -232 mg; Mn, 330 mg; Si, 30 mg; Ti, 71 mg; V, 1,288 mg; Y, 63 mg; and Zr, 134 mg.

The advantage of this study is that it provides quantitative estimates of soil ingestion for adults. The study also corrected for tracer concentrations in foods and medicines. However, a limitation of this study is that a limited number of subjects were studied. In addition, the subjects were only studied for one week before soil capsules were ingested.

4.5. PREVALENCE OF PICA

The scientific literature define pica as "the repeated eating of non-nutritive substances" (Feldman, 1986). For the purposes of this handbook, pica is defined as an deliberately high soil ingestion rate. Numerous articles have been published that report on the incidence of pica among various populations. However, most of these papers describe pica for substances other than soil including sand, clay, paint, plaster, hair, string, cloth, glass, matches, paper, feces, and various other items. These papers indicate that the pica occurs in approximately half of all children between the ages of 1 and 3 years (Sayetta, 1986). The incidence of deliberate ingestion behavior in children has been shown to differ for different subpopulations. The incidence rate appears to be higher for black children than for white children. Approximately 30 percent of black children aged 1 to 6 years are reported to have deliberate ingestion behavior, compared with 10 to 18 percent of white children in the same age group (Danford, 1982). There does not appear to be any sex differences in the incidence rates for males or females (Kaplan and Sadock, 1985). Lourie et al. (1963) states that the incidence of pica is higher among children in lower socioeconomic groups (i.e., 50 to 60 percent) than in higher income families (i.e., about 30 percent). Deliberate soil ingestion behavior appears to be more common in rural areas (Vermeer and Frate, 1979). A higher rate of pica has also been reported for pregnant women and individuals with poor nutritional status (Danford, 1982). In general, deliberate ingestion behavior is more frequent and more severe in mentally retarded children than in children in the general population (Behrman and Vaughan 1983, Danford 1982, Forfar and Arneil 1984, Illingworth 1983, Sayetta 1986).

It should be noted that the pica statistics cited above apply to the incidence of general pica and not soil pica. Information on the incidence of soil pica is limited, but it appears that soil pica is less common. A study by Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., earth-eating) was about 16 percent among children from a rural black community in Mississippi. However, geophagia was described as a cultural practice among the community surveyed and may not be representative of the general population. Average daily consumption of soil was estimated to be 50 g/day. Bruhn and Pangborn (1971) reported the incidence of pica for "dirt" to be 19 percent in children, 14 percent in pregnant women, and 3 percent in nonpregnant women. However, "dirt" was not clearly defined. The Bruhn and Pangborn (1971) study was conducted among 91 non-black, low income families of migrant agricultural workers in California. Based on the data from the five key tracer studies (Binder et al., 1986; Clausing et al., 1987; Van Wïjnen et

al., 1990; Davis et al., 1990; and Calabrese et al., 1989) only one child out of the more than 600 children involved in all of these studies ingested an amount of soil significantly greater than the range for other children. Although these studies did not include data for all populations and were representative of short-term ingestions only, it can be assumed that the incidence rate of deliberate soil ingestion behavior in the general population is low. However, it is incumbent upon the user to use the appropriate value for their specific study population.

4.6. DELIBERATE SOIL INGESTION AMONG CHILDREN

Information on the amount of soil ingested by children with abnormal soil ingestion behavior is limited. However, some evidence suggests that a rate on the order of 10 g/day may not be unreasonable.

Calabrese et al. (1991) - Evidence of Soil Pica Behavior and Quantification of Soil Ingestion - Calabrese et al. (1991) estimated that upper range soil ingestion values may range from approximately 5-7 grams/day. This estimate was based on observations of one pica child among the 64 children who participated in the study. In the study, a 3.5-year old female exhibited extremely high soil ingestion behavior during one of the two weeks of observation. Intake ranged from 74 mg/day to 2.2 g/day during the first week of observation and 10.1 to 13.6 g/day during the second week of observation (Table 4-18). These results are based on mass-balance analyses for seven (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, and yttrium) of the eight tracer elements used. Intake rates based on zirconium was significantly lower but Calabrese et al. (1991) indicated that this may have "resulted from a limitation in the analytical protocol."

Calabrese and Stanek (1992) - Distinguishing Outdoor Soil Ingestion from Indoor Dust Ingestion in a Soil Pica Child - Calabrese and Stanek (1992) quantitatively distinguished the amount of outdoor soil ingestion from indoor dust ingestion in a soil pica child. This study was based on a previous mass-balance study (conducted in 1991) in which a 3-1/2 year old child ingested 10-13 grams of soil per day over the second week of a 2-week soil ingestion study. Also, the previous study utilized a soil tracer methodology with eight different tracers (Al, Ba, Mn, Si, Ti, V, Y, Zr). The reader is referred to Calabrese et al. (1989) for a detailed description and results of the soil ingestion study. Calabrese and Stanek (1992) distinguished indoor dust from outdoor soil in ingested soil based on a methodology which compared differential element ratios.

Table 4-19 presents tracer ratios of soil, dust, and residual fecal samples in the soil pica child. Calabrese and Stanek (1992) reported that there was a maximum total of 28 pairs of tracer ratios based on eight tracers. However, only 19 pairs of tracer ratios were available for quantitative evaluation as shown in Table 4-19. Of these 19 pairs, 9 fecal

tracer ratios fell within the boundaries for soil and dust (Table 4-19). For these 9 tracer soils, an interpolation was performed to estimate the relative contribution of soil and dust to the residual fecal tracer ratio. The other 10 fecal tracer ratios that fell outside the soil and dust boundaries were concluded to be 100 percent of the fecal tracer ratios from soil origin (Calabrese and Stanek, 1992). Also, the 9 residual fecal samples within the boundaries revealed that a high percentage (71-99 percent) of the residual fecal tracers were estimated to be of soil origin. Therefore, Calabrese and Stanek (1992) concluded that the predominant proportion of the fecal tracers was from outdoor soil and not from indoor dust origin.

In conducting a risk assessment for TCDD, U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) also investigated the potential for exposure to TCDD through the soil ingestion route. CDC used a value of 10 g/day to represent the amount of soil that a child with deliberate soil ingestion behavior might ingest (Kimbrough et al., 1984). These values are consistent with those observed by Calabrese et al. (1991).

4.7. RECOMMENDATIONS

The key studies described in this section were used to recommend values for soil intake among children. The key and relevant studies used different survey designs and study populations. These studies are summarized in Table 4-20. For example, some of the studies considered food and nonfood sources of trace elements, while others did not. In other studies, soil ingestion estimates were adjusted to account for the contribution of house dust to this estimate. Despite these differences, the mean and upper-percentile estimates reported for these studies are relatively consistent. The confidence rating for soil intake recommendations is presented in Table 4-21.

It is important, however, to understand the various uncertainties associated with these values. First, individuals were not studied for sufficient periods of time to get a good estimate of the usual intake. Therefore, the values presented in this section may not be representative of long term exposures. Second, the experimental error in measuring soil ingestion values for individual children is also a source of uncertainty. For example, incomplete sample collection of both input (i.e., food and nonfood sources) and output (i.e., urine and feces) is a limitation for some of the studies conducted. In addition, an individual's soil ingestion value may be artificially high or low depending on the extent to which a mismatch between input and output occurs due to individual variation in the gastrointestinal transit time. Third, the degree to which the tracer elements used in these studies are absorbed in the human body is uncertain. Accuracy of the soil ingestion estimates depends on how good this assumption is. Fourth, there is uncertainty with regard to the homogeneity of soil samples and the accuracy of parent's knowledge about

their child's playing areas. Fifth, all the soil ingestion studies presented in this section with the exception of Calabrese et al. (1989) were conducted during the summer when soil contact is more likely.

Although the recommendations presented below are derived from studies which were mostly conducted in the summer, exposure during the winter months when the ground is frozen or snow covered should not be considered as zero. Exposure during these months, although lower than in the summer months, would not be zero because some portion of the house dust comes from outdoor soil.

Soil Ingestion Among Children - Estimates of the amount of soil ingested by children are summarized in Table 4-22. The mean values ranged from 39 mg/day to 271 mg/day with an average of 146 mg/day for soil ingestion and 191 mg/day for soil and dust ingestion. Results obtained using titanium as a tracer in the Binder et al. (1986) and Clausing et al. (1987) studies were not considered in the derivation of this recommendation because these studies did not take into consideration other sources of the element in the diet which for titanium seems to be significant. Therefore, these values may overestimate the soil intake. One can note that this group of mean values is consistent with the 200 mg/day value that EPA programs have used as a conservative mean estimate. Taking into consideration that the highest values were seen with titanium, which may exhibit greater variability than the other tracers, and the fact that the Calabrese et al. (1989) study included a pica child, 100 mg/day is the best estimate of the mean for children under 6 years of age. However, since the children were studied for short periods of time and the prevalence of pica behavior is not known, excluding the pica child from the calculations may underestimate soil intake rates. It is plausible that many children may exhibit some pica behavior if studied for longer periods of time. Over the period of study, upper percentile values ranged from 106 mg/day to 1,432 mg/day with an average of 383 mg/day for soil ingestion and 587 mg/day for soil and dust ingestion. Rounding to one significant figure, the recommended upper percentile soil ingestion rate for children is 400 mg/day. However, since the period of study was short, these values are not estimates of usual intake. The recommended values for soil ingestion among children and adults are summarized in Table 4-23.

Data on soil ingestion rates for children who deliberately ingest soil are also limited. An ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information. It should be noted, however, that this value is based on only one pica child observed in the Calabrese et al. (1989) study.

Soil Ingestion Among Adults - Only three studies have attempted to estimate adult soil ingestion. Hawley (1985) suggested a value of 480 mg/day for adults engaged in outdoor activities and a range of 0.56 to 110 mg/day of house dust during indoor activities. These

estimates were derived from assumptions about soil/dust levels on hands and mouthing behavior; no supporting measurements were made. Making further assumptions about frequencies of indoor and outdoor activities, Hawley (1985) derived an annual average of 60.5 mg/day. Given the lack of supporting measurements, these estimates must be considered conjectural. Krablin (1989) used arsenic levels in urine (n=26) combined with information on mouthing behavior and activity patterns to suggest an estimate for adult soil ingestion of 10 mg/day. The study protocols are not well described and has not been formally published. Finally, Calabrese et al. (1990) conducted a tracer study on 6 adults and found a range of 30 to 100 mg/day. This study is probably the most reliable of the three, but still has two significant uncertainties: (1) representativeness of the general population is unknown due to the small study size (n=6); and (2) representativeness of long-term behavior is unknown since the study was conducted over only 2 weeks. In the past, many EPA risk assessments have assumed an adult soil ingestion rate of 50 mg/day for industrial settings and 100 mg/day for residential and agricultural scenarios. These values are within the range of estimates from the studies discussed above. Thus, 50 mg/day still represents a reasonable central estimate of adult soil ingestion and is the recommended value in this handbook. This recommendation is clearly highly uncertain; however, and as indicated in Table 4-21, is given a low confidence rating. Considering the uncertainties in the central estimate, a recommendation for an upper percentile value would be inappropriate. Table 4-23 summarizes soil ingestion recommendations for adults.

Table 4-1. Estimated Daily Soil Ingestion Based on Aluminum, Silicon, and Titanium Concentrations

Estimation Method	Mean (mg/day)	Median (mg/day)	Standard Deviation (mg/day)	Range (mg/day)	95th Percentile (mg/day)	Geometric Mean (mg/day)
Aluminum	181	121	203	25-1,324	584	128
Silicon	184	136	175	31-799	5,78	130
Titanium	1,834	618	3,091	4-17,076	9,590	401
Minimum	108	88	121	4-708	386	65

Source: Binder et al., 1986.

Table 4-2. Calculated Soil Ingestion by Nursery School Children

Child	Sample Number	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Soil Ingestion as Calculated from AIR (mg/day)	Limiting Tracer (mg/day)
1	L3	103	300	107	103
	L14	154	211	172	154
	L25	130	23	-	23
2	L5	131	-	71	71
	L13	184	103	82	82
	L27	142	81	84	81
3	L2	124	42	84	42
	L17	670	566	174	174
4	L4	246	62	145	62
	L11	2,990	65	139	65
5	L8	293	-	108	108
	L21	313	-	152	152
6	L12	1,110	693	362	362
	L16	176	-	145	145
7	L18	11,620	-	120	120
	L22	11,320	77	-	77
8	L1	3,060	82	96	82
9	L6	624	979	111	111
10	L7	600	200	124	124
11	L9	133	-	95	95
12	L10	354	195	106	106
13	L15	2,400	-	48	48
14	L19	124	71	93	71
15	L20	269	212	274	212
16	L23	1,130	51	84	51
17	L24	64	566	-	64
18	L26	184	56	-	56
Arithmetic Mean		1,431	232	129	105

Source: Adapted from Clausing et al. 1987.

Table 4-3. Calculated Soil Ingestion by Hospitalized, Bedridden Children

Child	Sample	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Limiting Tracer (mg/day)
1	G5	3,290	57	57
	G6	4,790	71	71
2	G1	28	26	26
3	G2	6,570	94	84
	G8	2,480	57	57
4	G3	28	77	28
5	G4	1,100	30	30
6	G7	58	38	38
Arithmetic Mean		2,293	56	49

Source: Adapted from Clausing et al. 1987.

Table 4-4. Mean and Standard Deviation Percentage Recovery of Eight Tracer Elements

	300 mg Soil Ingested		1500 mg Soil Ingested	
Tracer Element	Mean	SD	Mean	SD
Al	152.8	107.5	93.5	15.5
Ba	2304.3	4533.0	149.8	69.5
Mn	1177.2	1341.0	248.3	183.6
Si	139.3	149.6	91.8	16.6
Ti	251.5	316.0	286.3	380.0
V	345.0	247.0	147.6	66.8
Y	120.5	42.4	87.5	12.6
Zr	80.6	43.7	54.6	33.4

Source: Adapted from Calabrese et al., 1989.

Table 4-5. Soil and Dust Ingestion Estimates for Children Aged 1-4 Years

Tracer Element	N	Intake (mg/day)[a]				
		Mean	Median	SD	95th Percentile	Maximum
Aluminum						
soil	64	153	29	852	223	6,837
dust	64	317	31	1,272	506	8,462
soil/dust combined	64	154	30	629	478	4,929
Silicon						
soil	64	154	40	693	276	5,549
dust	64	964	49	6,848	692	54,870
soil/dust combined	64	483	49	3,105	653	24,900
Yttrium						
soil	62	85	9	890	106	6,736
dust	64	62	15	687	169	5,096
soil/dust combined	62	65	11	717	159	5,269
Titanium						
soil	64	218	55	1,150	1,432	6,707
dust	64	163	28	659	1,266	3,354
soil/dust combined	64	170	30	691	1,059	3,597

[a] Corrected for Tracer Concentrations in Foods

Source: Adapted from Calabrese et al., 1989.

Table 4-6. Average Daily Soil Ingestion Values Based on Aluminum, Silicon, and Titanium as Tracer Elements[a]

Element	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
Minimum	38.9	25.3	12.2	-5,820.8
Maximum	245.5	81.3	119.7	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 nonsoil sources of the tracer elements.
Source: Adapted from Davis et al., 1990.

Table 4-7. Geometric Mean (GM) and Standard Deviation (GSD) LTM Values for Children at Daycare Centers and Campgrounds

Age (yrs)	Sex	Daycare Centers			Campgrounds		
		n	GM LTM (mg/day)	GSD LTM (mg/day)	n	GM LTM (mg/day)	GSD LTM (mg/day)
<1	Girls	3	81	1.09	-	-	-
	Boys	1	75	-	-	-	-
1-<2	Girls	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2-<3	Girls	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3-4	Girls	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4-<5	Girls	1	180	-	19	164	1.48
	Boys	4	99	1.62	18	136	1.30
All girls		86	117	1.70	36	179	1.67
All boys		72	104	1.46	42	169	1.79
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.
Source: Adapted from Van Wijnen et al., 1990.

Table 4-8. Estimated Geometric Mean LTM Values of Children Attending Daycare Centers According to Age, Weather Category, and Sampling Period

Weather Category	Age (years)	First Sampling Period		Second Sampling Period	
		n	Estimated Geometric Mean LTM Value (mg/day)	n	Estimated Geometric Mean LTM Value (mg/day)
Bad	<1	3	94	3	67
(>4 days/week precipitation)	1-<2	18	103	33	80
	2-<3	33	109	48	91
	4-<5	5	124	6	109
Reasonable	<1			1	61
(2-3 days/week precipitation)	1-<2			10	96
	2-<3			13	99
	3-<4			19	94
	4-<5			1	61
Good	<1	4	102		
(<2 days/week precipitation)	1-<2	42	229		
	2-<3	65	166		
	3-<4	67	138		
	4-<5	10	132		

Source: Van Wijnen et al., 1990.

Table 4-9. Distribution of Average (Mean) Daily Soil Ingestion Estimates Per Child for 64 Children[a] (mg/day)

Type of Estimate Number of Samples	Overall (64)	A1 (64)	Ba (33)	Mn (19)	Si (63)	Ti (56)	V (52)	Y (61)	Zr (62)
Mean	179	122	655	1,053	139	271	112	165	23
25th Percentile	10	10	28	35	5	8	8	0	0
50th Percentile	45	19	65	121	32	31	47	15	15
75th Percentile	88	73	260	319	94	93	177	47	41
90th Percentile	186	131	470	478	206	154	340	105	87
95th Percentile	208	254	518	17,374	224	279	398	144	117
Maximum	7,703	4,692	17,991	17,374	4,975	12,055	845	8,976	208

[a] For each child, estimates of soil ingestion were formed on days 4-8 and the mean of these estimates was then evaluated for each child. The values in the column "overall" correspond to percentiles of the distribution of these means over the 64 children. When specific trace elements were not excluded via the relative standard deviation criteria, estimates of soil ingestion based on the specific trace element were formed for 108 days for each subject. The mean soil ingestion estimate was again evaluated. The distribution of these means for specific trace elements is shown.

Source: Stanek and Calabrese, 1995a.

Table 4-10. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected Over 365 Days[a]

Range	1 - 2,268 mg/d[b]
50th Percentile (median)	75 mg/d
90th Percentile	1,190 mg/d
95th Percentile	1,751 mg/d

[a] Based on fitting a log-normal distribution to model daily soil ingestion values.
[b] Subject with pica excluded.
Source: Stanek and Calabrese, 1995a.

Table 4-11. Estimates of Soil Ingestion for Children

Scenarios	Media	Exposure (mg/day)	Days/Year Activity	Fraction Soil Content	Annual Average Soil Intake (mg/day)
Young Child (2.5 Years Old)					
Outdoor Activities (Summer)	Soil	250	130	1	90
Indoor Activities (Summer)	Dust	50	182	0.8	20
Indoor Activities (Winter	Dust	100	182	0.8	40
TOTAL SOIL INTAKE					150
Older Child (6 Years Old)					
Outdoor Activities (Summer)	Soil	50	152	1	21
Indoor Activities (Year-Round)	Dust	3	365	0.8	2.4
TOTAL SOIL INTAKE					23.4

Source: Hawley, 1985.

Table 4-12. Estimated Soil Ingestion Rate Summary Statistics and Parameters for Distributions Using Binder et al. (1986) Data with Actual Fecal Weights

Trace Element Basis	Soil Intake (mg/day)			
	A1	Si	Ti	MEAN[a]
Mean	97	85	1,004	91
Min	11	10	1	13
10th	21	19	3	22
20th	33	23	22	34
30th	39	36	47	43
40th	43	52	172	49
Med	45	60	293	59
60th	55	65	475	69
70th	73	79	724	92
80th	104	106	1,071	100
90th	197	166	2,105	143
Max	1,201	642	14,061	921
	Lognormal Distribution Parameters			
Median	45	60	--	59
Standard Deviation	169	95	--	126
Arithmetic Mean	97	85	--	91
	Underlying Normal Distribution Parameters			
Mean	4.06	4.07	--	4.13
Standard Deviation	0.88	0.85	--	0.80

[a] MEAN = arithmetic average of soil ingestion based on aluminum and silicon.
Source: Thompson and Burmaster, 1991.

Table 4-13. Tukey's Multiple Comparison of Mean Log Tracer Recovery in Adults Ingesting Known Quantities of Soil

Tracer	Reported Mean (mg/day)	Age Adjusted Mean (mg/day)
	Calabrese et al., 1989 Study	
Aluminum	153	160
Silicon	154	161
Titanium	218	228
Vanadium	459	480
Yttrium	85	89
	Davis et al., 1990 Study	
Aluminum	39	53
Silicon	81	111
Titanium	246	333

[a] Age adjusted mean estimates of soil ingestion in young children. Mean estimates of soil ingestion for each tracer in each study were adjusted using the following equation:

$Y = x\, e^{(-0.112 * yr)}$, where Y = adjusted mean soil ingestion (mg/day), x = a constant, and yr = age in years.

Source: Sedman and Mahmood, 1994.

Table 4-14. Positive/Negative Error (bias) in Soil Ingestion Estimates in the Calabrese et al. (1989) Mass-balance Study: Effect on Mean Soil Ingestion Estimate (mg/day)[a]

	Negative Error						
	Lack of Fecal Sample on Final Study Day	Other Causes[b]	Total Negative Error	Total Positive Error	Net Error	Original Mean	Adjusted Mean
Aluminum	14	11	25	43	+18	153	136
Silicon	15	6	21	41	+20	154	133
Titanium	82	187	269	282	+13	218	208
Vanadium	66	55	121	432	+311	459	148
Yttrium	8	26	34	22	-12	85	97
Zirconium	6	91	97	5	-92	21	113

[a] How to read table: for example, aluminum as a soil tracer displayed both negative and positive error. The cumulative total negative error is estimated to bias the mean estimate by 25 mg/day downward. However, aluminum has positive error biasing the original mean upward by 43 mg/day. The net bias in the original mean was 18 mg/day positive bias. Thus, the original 156 mg/day mean for aluminum should be corrected downward to 136 mg/day.

[b] Values indicate impact on mean of 128-subject-weeks in milligrams of soil ingested per day.

Source: Calabrese and Stanek, 1995.

Table 4-15. Soil Ingestion Rates for Assessment Purposes

Receptor Age	Setting	Soil Load on Hands (mg/cm^2)	Soil Exposure Ingestion Rate (mg/hr)	Suggested Exposure Durations (hr/yr)	Average Daily Soil Ingestion (mg/day)
Pica Child		---	1,000	200	500
2.5 yrs	Outdoor	0.5	20	1,000	50
	Indoor	0.4	3	Remaining[a]	60
6 yrs	Outdoor	0.5	10	700	20
	Indoor	0.04	0.15	5,000	2
Adult	Gardening	1.0	20	300	20
	Indoor	0.04	0.03	5,000	0.4

[a] Hawley (1985) assumed the child spent all the time at home, so that the indoor time was 8,760 hours/year minus the outdoor time.
Source: Sheppard, 1995

Table 4-16. Estimates of Soil Ingestion for Adults

Scenarios	Media	Exposure (mg/day)	Days/Year Activity	Fraction Soil Content	Annual Average Soil Intake (mg/day)
Adult					
Work in attic (year-round)	Dust	110	12	0.8	3
Living Space (year-round)	Dust	0.56	365	0.8	0.5
Outdoor Work (summer)	Soil	480	43	1	57
TOTAL SOIL INTAKE					60.5

Source: Hawley, 1985.

Table 4-17. Adult Daily Soil Ingestion Estimates by Week and Tracer Element After Subtracting Food and Capsule Ingestion, Based on Median Amherst Soil Concentrations: Means and Medians Over Subjects (mg)[a]

Week	Al	Ba	Mn	Si	Ti	V	Y	Zr
Means								
1	110	-232	330	30	71	1,288	63	134
2	98	12,265	1,306	14	25	43	21	58
3	28	201	790	-23	896	532	67	-74
Medians								
1	60	-71	388	31	102	1,192	44	124
2	85	597	1,368	15	112	150	35	65
3	66	386	831	-27	156	047	60	-144

[a] Data were converted to milligrams
[b] Negative values occur because of correction for food and capsule ingestion.
Source: Calabrese et al., 1990

Table 4-18. Daily Soil Ingestion Estimation in a Soil-Pica Child by Tracer and by Week (mg/day)

Tracer	Week 1 Estimated Soil Ingestion	Week 2 Estimated Soil Ingestion
Al	74	13,600
Ba	458	12,088
Mn	2,221	12,341
Si	142	10,955
Ti	1,543	11,870
V	1,269	10,071
Y	147	13,325
Zr	86	2,695

Source: Calabrese et al., 1991

Table 4-19. Ratios of Soil, Dust, and Residual Fecal Samples in the Soil Pica Child

Tracer Ratio Pairs		Soil	Fecal	Dust	Estimated % of Residual Fecal Tracers of Soil Origin as Predicted by Specific Tracer Ratios
1.	Mn/Ti	208.368	215.241	260.126	87
2.	Ba/Ti	187.448	206.191	115.837	100
3.	Si/Ti	148.117	136.662	7.490	92
4.	V/Ti	14.603	10.261	17.887	100
5.	Ai/Ti	18.410	21.087	13.326	100
6.	Y/Ti	8.577	9.621	5.669	100
7.	Mn/Y	24.293	22.373	45.882	100
8.	Ba/Y	21.854	21.432	20.432	71
9.	Si/Y	17.268	14.205	1.321	81
10.	V/Y	1.702	1.067	3.155	100
11.	Al/Y	2.146	2.192	2.351	88
12.	Mn/Al	11.318	10.207	19.520	100
13.	Ba/Al	10.182	9.778	8.692	73
14.	Si/Al	8.045	6.481	0.562	81
15.	V/Al	0.793	0.487	1.342	100
16.	Si/V	10.143	13.318	0.419	100
17.	Mn/Si	1.407	1.575	34.732	99
18.	Ba/Si	1.266	1.509	15.466	83
19.	Mn/Ba	1.112	1.044	2.246	100

Source: Calabrese and Stanek, 1992.

Table 4-20. Soil Intake Studies

Study	Study Type	Number of Observations	Population Studied: Age	Population Studied:	Comments
CHILDREN KEY STUDIES:					
Binder et al., 1986	Tracer study using aluminum, silicon, and titanium	59 children	1-3 years	Children living near lead smelter in Montana	Did not account for tracer in food and medicine; used assumed fecal weight of 15 g/day; short-term study conducted over 3 days
Calabrese et al., 1989	Tracer - mass balance study using aluminum, barium, manganese, silicon, titanium, vanadium, ytrium, and zirconium	64 Children	1-4 years	Children from greater Amherst area of Massachusetts; highly-educated parents	Corrected for tracer in food and medicine; study conducted over two-week period; used adults to validate methods; one pica child in study group.
Clausing et al., 1987	Tracer study using aluminum, acid insoluble residue, and titanium	18 nursery school children; 6 hospitalized children	2-4 years	Dutch children	Did not account for tracer in food and medicines; used tracer-based intake rates for hospitalized children as background values; short-term study conducted over 5 days
Davis et al., 1990	Tracer - mass balance study using aluminum silicon and titanium	104 children	2-7 years	Children from 3-city area in Washington State	Corrected for tracer in food and medicine; short-term study conducted over seven-day period; collected information on demographic characteristics affecting soil intake.
Stanek and Calabrese, 1995a	Adjusted soil intake estimates	64 children	1-4 years	Same children as in Calabrese et al., 1989	Based on data from Calabrese et al., 1989
Stanek and Calabrese, 1995b	Recalculated intake rates based on three previous mass-balance studies using the Best Tracer Method	164 children 6 adults	1-7 years 25-41 years	Children from three mass-balance studies	Based on studies of Calabrese et al., 1989; Davis et al., 1990; and Calabrese et al., 1990.
Van Wïjnen et al., 1990	Tracer study using aluminum, acid insoluble residue, and titanium	292 daycare children; 78 campers; 15 hospitalized children	1-5 years	Dutch children	Did not account for tracer in food and medicines; used tracer-based intake for hospitalized children as background values; evaluated population (campers) with greater access to soil; evaluated differences in soil intake due to weather conditions.
CHILDREN RELEVANT STUDIES:					
AIHC, 1994	Reanalysis of data from Calabrese et al., 1990	6 adults	21-41 years	Health adults	Used data from Calabrese et al. (1990) study to derive soil ingestion rates using zirconium as a tracer; recent studies indicate that zirconium is not a good tracer
Calabrese and Stanek, 1995	Evaluated errors in soil ingestion estimates	64 children	1-4 years	Study population of Calabrese et al., 1989	Based on Calabrese et al., 1989 data.

Table 4-20. Soil Intake Studies (continued)

Study	Study Type	Number of Observations	Population Studied: Age	Population Studied:	Comments
CHILDREN RELEVANT STUDIES (continued):					
Day et al., 1977	Measured dirt on sticky sweets and assumed number of sweets eaten per day	Not specified	Not specified	Not specified	Based on observations and crude measurements.
Duggan and Williams, 1977	Measured soil on fingers and observed mouthing behavior	Not specified	Not specified	Areas around London	Based on observations and crude measurements.
Hawley, 1985	Assumed soil intake rates based on nature and duration of activities	Not specified	Young children, older children, adults	Not specified	No data on soil intake collected; estimates based on assumptions regarding data from previous studies.
Lepow et al., 1974; 1975	Measured soil on hands and observed mouthing behavior	22 children	2-6 years	Urban children from Connecticut	Based on observations over 3-6 hours of play and crude measurement techniques.
Sedman and Mahmood, 1994	Adjusted data from earlier tracer-mass balance studies to generate mean soil intake rates for a 2-year old child	64 children from Calabrese et al., 1989 study and 104 children from Davis et al., 1990 study	Adjusted to 2-year old child	Same children as in Calabrese et al., 1989 and Davis et al., 1990 study	Based on data from Calabrese et al., 1989 and Davis et al., 1990.
Sheppard, 1995	Provides estimates based on the current literature on soil ingestion from tracer methods and recommends values for use in assessments	Not specified	1 year-adults (age not specified)	Various	Presents mean estimates for children and adults; provides ingestion estimates for indoor and outdoor activities based on Hawley, 1985.
Thompson and Burmaster, 1991	Re-evaluation of Binder et al., 1986 data	59 children	1-3 years	Children living near lead smelter in Montana	Re-calculated soil intake rates from Binder et al., 1986 data using actual fecal weights instead of assumed weights.
ADULT SOIL INTAKE STUDIES:					
Hawley, 1985	Assumed soil intake rates based on nature and duration of activities	Not specified	Young children, older children, adults	Not specified	No data on soil intake collected; estimates based on assumptions regarding data from previous studies.
Calabrese et al., 1990	Measured excretory output after ingestion of capsules with sterilized soil	6 adults	21-41 years	Healthy adult volunteers	Data used to validate the analytical methodology used in the children's study (Calabrese, 1989).
PICA STUDIES:					
Calabrese et al., 1991	Tracer - mass balance	1 pica child	3.5 years	1 pica child from greater Amherst area of Massachusetts	Child was observed as part of the Calabrese et al., 1989 study.
Calabrese and Stanek, 1992	Reanalysis of data from Calabrese et al., 1991	1 pica child	3.5 years	1 pica child from greater Amherst area of Massachusetts	Distinguished between outdoor soil ingestion and indoor dust ingestion in a soil pica child.

Table 4-21. Confidence in Soil Intake Recommendation		
Considerations	Rationale	Rating
Study Elements		
• Level of peer review	All key studies are from peer review literature.	High
• Accessibility	Papers are widely available from peer review journals.	High
• Reproducibility	Methodology used was presented, but results are difficult to reproduce.	Medium
• Focus on factor of interest	The focus of the studies was on estimating soil intake rate by children; studies did not focus on intake rate by adults.	High (for children) Low (for adults)
• Data pertinent to U.S.	Two of the key studies focused on Dutch children; other studies used children from specific areas of the U.S.	Medium
• Primary data	All the studies were based on primary data.	High
• Currency	Studies were conducted after 1980.	High
• Adequacy of data collection period	Children were not studied long enough to fully characterize day to day variability.	Medium
• Validity of approach	The basic approach is the only practical way to study soil intake, but refinements are needed in tracer selection and matching input with outputs. The more recent studies corrected the data for sources of the tracers in food. There are, however, some concerns about absorption of the tracers into the body and lag time between input and output.	Medium
• Study size	The sample sizes used in the key studies were adequate for children. However, only few adults have been studied.	Medium (for children) Low (for adults)
• Representativeness of the population	The study population may not be representative of the U.S. in terms of race, socio-economics, and geographical location; Studies focused on specific areas; two of the studies used Dutch children.	Low
• Characterization of variability	Day-to-day variability was not very well characterized.	Low
• Lack of bias in study design (high rating is desirable)	The selection of the population studied may introduce some bias in the results (i.e., children near a smelter site, volunteers in nursery school, Dutch children).	Medium
• Measurement error	Errors may result due to problems with absorption of the tracers in the body and mismatching inputs and outputs.	Medium
Other Elements		
• Number of studies	There are 7 key studies.	High
• Agreement between researchers	Despite the variability, there is general agreement among researchers on central estimates of daily intake for children.	Medium
Overall Rating	Studies were well designed; results were fairly consistent; sample size was adequate for children and very small for adults; accuracy of methodology is uncertain; variability cannot be characterized due to limitations in data collection period. Insufficient data to recommend upper percentile estimates for both children and adults.	Medium (for children - long-term central estimate) Low (for adults) Low (for upper percentile)

Table 4-22. Summary of Estimates of Soil Ingestion by Children

Mean (mg/day)					Upper Percentile (mg/day)				References
Al	Si	AIR[a]	Ti	Y	Al	Si	Ti	Y	
181	184				584	578			Binder et al. 1986
230		129							Clausing et al. 1987
39	82		245.5						Davis et al. 1990
64.5[b]	160[b]		268.4[b]						
153	154		218	85	223	276	1,432	106	Calabrese et al. 1989
154[b]	483[b]		170[b]	65[b]	478[b]	653[b]	1,059[b]	159[b]	
122	139	--	271	165	254	224	279	144	Stanek and Calabrese, 1995a
133[c]					217[c]				Stanek and Calabrese, 1995b
69-120[d]									Van Wijnen et al. 1990
Average =	146 mg/day soil 191 mg/day soil and dust combined				383 mg/day soil 587 mg/day soil and dust combined				

[a] AIR = Acid Insoluble Residue
[b] Soil and dust combined
[c] BTM
[d] LTM; corrected value

Table 4-23. Summary of Recommended Values for Soil Ingestion

Population	Mean	Upper Percentile
Children	100 mg/day[a]	400 mg/day[b]
Adults	50 mg/day	--
Pica child	10 g/day[c]	---

[a] 200 mg/day may be used as a conservative estimate of the mean (see text).
[b] Study period was short; therefore, these values are not estimates of usual intake.
[c] To be used in acute exposure assessments. Based on only one pica child (Calabrese et al., 1989).

REFERENCES FOR CHAPTER 4

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. AIHC, Washington, DC.

Binder, S.; Sokal, D.; Maughan, D. (1986) Estimating soil ingestion: the use of tracer elements in estimating the amount of soil ingested by young children. Arch. Environ. Health. 41(6):341-345.

Behrman, L.E.; Vaughan, V.C., III. (1983) Textbook of Pediatrics. Philadelphia, PA: W.B. Saunders Company.

Bruhn, C.M.; Pangborn, R.M. (1971) Reported incidence of pica among migrant families. J. of the Am. Diet. Assoc. 58:417-420.

Calabrese, E.J.; Kostecki, P.T.; Gilbert, C.E. (1987) How much soil do children eat? An emerging consideration for environmental health risk assessment. In press (Comments in Toxicology).

Calabrese, E.J.; Pastides, H.; Barnes, R.; Edwards, C.; Kostecki, P.T.; et al. (1989) How much soil do young children ingest: an epidemiologic study. In: Petroleum Contaminated Soils, Lewis Publishers, Chelsea, MI. pp. 363-397.

Calabrese, E.J.; Stanek, E.J.; Gilbert, C.E.; Barnes, R.M. (1990) Preliminary adult soil ingestion estimates; results of a pilot study. Regul. Toxicol. Pharmacol. 12:88-95.

Calabrese, E.J.; Stanek, E.J.; Gilbert, C.E. (1991) Evidence of soil-pica behavior and quantification of soil ingested. Hum. Exp. Toxicol. 10:245-249.

Calabrese, E.J.; Stanek, E.J. (1992) Distinguishing outdoor soil ingestion from indoor dust ingestion in a soil pica child. Regul. Toxicol. Pharmacol. 15:83-85.

Calabrese, E.J.; Stanek, E.J. (1995) Resolving intertracer inconsistencies in soil ingestion estimation. Environ. Health Perspect. 103(5):454-456.

Clausing, P.; Brunekreef, B.; Van Wijnen, J.H. (1987) A method for estimating soil ingestion by children. Int. Arch. Occup. Environ. Health (W. Germany) 59(1):73-82.

Danford, D.C. (1982) Pica and nutrition. Annual Review of Nutrition. 2:303-322.

Davis, S.; Waller, P.; Buschbon, R.; Ballou, J.; White, P. (1990) Quantitative estimates of soil ingestion in normal children between the ages of 2 and 7 years: population based estimates using aluminum, silicon, and titanium as soil tracer elements. Arch. Environ. Hlth. 45:112-122.

Day, J.P.; Hart, M.; Robinson, M.S. (1975) Lead in urban street dust. Nature 253:343-345.

Duggan, M.J.; Williams, S. (1977) Lead in dust in city streets. Sci. Total Environ. 7:91-97.

Feldman, M.D. (1986) Pica: current perspectives. Psychosomatics (USA) 27(7):519-523.

Forfar, J.O.; Arneil, G.C., eds. (1984) Textbook of Paediatrics. 3rd ed. London: Churchill Livingstone.

Hawley, J.K. (1985) Assessment of health risk from exposure to contaminated soil. Risk Anal. 5:289-302.

Illingworth, R.S. (1983) The normal child. New York: Churchill Livingstone.

Kaplan, H.I.; Sadock, B.J. (1985) Comprehensive textbook of psychiatry/IV. Baltimore, MD: Williams and Wilkins.

Kimbrough, R.; Falk, H.; Stemr, P.; Fries, G. (1984) Health implications of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) contamination of residential soil. J. Toxicol. Environ. Health 14:47-93.

Krablin, R. (1989) [Letter to Jonathan Z. Cannon concerning soil ingestion rates.] Denver, CO: Arco Coal Co.; October 13, 1989.

Lepow, M.L.; Bruckman, L.; Robino, R.A.; Markowitz, S.; Gillette, M.; et al. (1974) Role of airborne lead in increased body burden of lead in Hartford children. Environ. Health Perspect. 6:99-101.

Lepow, M.L.; Bruckman, L.; Gillette, M.; Markowitz, S.; Robino, R.; et al. (1975) Investigations into sources of lead in the environment of urban children. Environ. Res. 10:415-426.

Lourie, R.S.; Layman, E.M.; Millican, F.K. (1963) Why children eat things that are not food. Children 10:143-146.

Roels, H.; Buchet, J.P.; Lauwerys, R.R. (1980) Exposure to lead by the oral and pulmonary route of children living in the vicinity of a primary lead smelter. Environ. Res. 22:81-94.

Sayetta, R.B. (1986) Pica: An overview. American Family Physician 33(5):181-185.

Sedman, R.; Mahmood, R.S. (1994) Soil ingestion by children and adults reconsidered using the results of recent tracer studies. Air and Waste, 44:141-144.

Sheppard, S.C. (1995) Parameter values to model the soil ingestion pathway. Environmental Monitoring and Assessment 34:27-44.

Stanek, E.J.; Calabrese, E.J. (1995a) Daily estimates of soil ingestion in children. Environ. Health Perspect. 103(3):276-285.

Stanek, E.J.; Calabrese, E.J. (1995b) Soil ingestion estimates for use in site evaluations based on the best tracer method. Human and Ecological Risk Assessment. 1:133-156.

Thompson, K.M.; Burmaster, D.E. (1991) Parametric distributions for soil ingestion by children. Risk Analysis. 11:339-342.

U.S. EPA. (1984) Risk analysis of TCDD contaminated soil. Washington, DC: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. EPA 600/8-84-031.

Van Wijnen, J.H.; Clausing, P.; Brunekreff, B. (1990) Estimated soil ingestion by children. Environ. Res. 51:147-162.

Vermeer, D.E.; Frate, D.A. (1979) Geophagia in rural Mississippi: environmental and cultural contexts and nutritional implications. Am. J. Clin. Nutr. 32:2129-2135.

DOWNLOADABLE TABLES FOR CHAPTER 4

The following selected tables are available for download as Lotus 1-2-3 worksheets.

Table 4-9. Distribution of Average (Mean) Daily Soil Ingestion Estimates Per Child for 64 Children (mg/day) [WK1, 3 kb]

Table 4-10. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected Over 365 Days [WK1, 1 kb]