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5. SOIL INGESTION AND PICA

5.1 INTRODUCTION

The ingestion of soil is a potential source of human exposure to toxicants. Some people are surprised to learn that soil ingestion occurs at all, and others are surprised to learn that some people ingest soil intentionally, due to cravings or cultural practices. Children may ingest significant quantities of soil, due to their tendency to play on floors and on the ground outdoors and due to their mouthing behaviors.

At this point in time, knowledge of soil ingestion patterns within the United States is somewhat limited. Only a few researchers in the U.S. have attempted to quantify soil ingestion patterns in children, and these researchers have performed studies in only a few locales in the northern parts of the United States. Based on the information that we do have, it appears that children may ingest fairly substantial amounts of soil on a per-kilogram-body-weight basis, and could receive a large proportion of their total exposure to certain toxicants via the soil ingestion route. Thus, understanding soil ingestion patterns is an important part of understanding, and estimating, children's overall exposures to environmental toxicants.

The Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (ATSDR) held a workshop in June 2000 in which a panel of soil ingestion experts developed definitions for soil ingestion, soil-pica, and geophagy, to distinguish aspects of soil ingestion patterns that are important from a research perspective (ATSDR 2001):

Soil ingestion is the consumption of soil. This may be intentional or unintentional, resulting from various behaviors including, but not limited to, mouthing, contacting dirty hands, eating dropped food, or consuming soil directly.

Soil ingestion, as defined above, has been documented in U.S. children in several studies that use a "tracer element" methodology. The tracer element methodology attempts to quantify amounts of soil ingested by analyzing samples of soil from childrens' residences, and by analyzing samples of the childrens' excreta (feces, and sometimes also urine). The soil, fecal, and urine samples are analyzed for the presence and quantity of tracer elements - typically, aluminum, silicon, titanium, and yttrium, and other elements. Because these metals/metalloids are not metabolized into other substances in the body, their presence in feces and urine can be used to estimate the quantity of soil ingested by mouth. None of the studies attempt to quantify amounts excreted in perspiration, tears, glandular secretions, hair or nails. Early versions of this methodology usually did not account for the contribution of tracer elements from non-soil substances (food, medications, and non-food sources such as toothpaste) that children might swallow. Later studies generally account for tracer element contributions from these non-soil sources.

Some study authors adjust their soil ingestion estimate results to account for the potential contribution of tracer elements found in household dust as well as soil. Dust is the fine particulate found indoors. It is composed of particles derived from outdoor sources such as soils, smoke, pollen, etc. and indoor sources such as particles associated with construction activities, wood burning, clothes drying, molds, etc. Dust ingestion can occur from inhalation, deposition in the respiratory system and subsequent ingestion.

Soil-pica is a form of soil ingestion that is characterized by the recurrent ingestion of unusually high amounts of soil (i.e., on the order of 1,000 - 5,000 milligrams per day). The soil ingestion may be intentional or unintentional.

Soil-pica, as defined above, has been documented in U.S. children with the same tracer element methodology, but to a more limited extent (Calabrese et al., 1991), and documented in Jamaican children (Wong 1988 as reported in Calabrese and Stanek 1993). The existing U.S. studies on soil ingestion, which appear to include some study subjects who exhibited soil-pica behavior, were of short duration, and had relatively small numbers of study participants. These factors combined may obscure the true incidence of soil-pica in the population of U.S. children. Groups at risk of soil-pica behavior include children aged 6 years and younger and individuals who are developmentally delayed. It should be noted that pica behavior is not always associated with developmentally impaired children and that pica behavior is observed in 50% of children between 1 and 3 years of age (Sayetta, 1986).

Geophagy is a form of soil ingestion defined as the intentional ingestion of earths and is usually associated with cultural practices.

Geophagy is practiced in various places in the United States by members of various cultural groups. It often involves the intentional ingestion of clay materials from uncontaminated sources that are not surface soils (ATSDR 2001, Vermeer and Frate, 1979). However, because geophagy is defined above as the intentional ingestion of clay or earths, and because determining whether a child's soil ingestion is intentional or not is difficult (ATSDR 2001), geophagy is not included as a separate concept in the rest of this chapter.

The available studies on soil intake are summarized in the following sections. Some of the later studies are re-analyses of data previously published. For this reason, the sections that follow are organized into studies of primary analysis and studies of secondary analysis. Within those two categories, there are studies considered "key" because their experimental design is superior, or they are the only studies with a particular attribute needed for the recommendations. The studies not categorized as "key" are categorized as "relevant" either because they are based on foreign data or because of limitations in the experimental design (e.g., not accounting for tracers found in food and medicines). Recommended soil intake rates are based on the results of key studies and are summarized in the last section, along with additional guidance to risk assessors using soil intake estimates.

5.2 SOIL INTAKE STUDIES

5.2.1 Key Studies of Primary Analysis

5.2.1.1 Davis *et al.*, 1990

Davis *et al.* (1990) 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 analyzing soil and house dust, feces, urine, and duplicate food samples for aluminum, silicon, and titanium. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil intake rates among children. The amount of soil ingested on a daily basis was estimated using the following equation:

$$S_{i.e} = \frac{(((DW_f + DW_P) \times E_f) + 2E_u) - (DW_{fd} \times E_{fd})}{E_{soil}} \qquad (5\text{-}2)$$

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 5-1). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. The investigators 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. The investigators also observed that the following demographic characteristics were associated with high soil intake rates: male sex, racial groups other than white, low income, operator/laborer as the principal occupation of the parent, and city of residence. However, none of these factors were predictive of soil intake rates when tested using multiple linear regression.

The advantages of this 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.

5.2.1.2 Calabrese *et al.* 1997a

Calabrese *et al.* (1997a) estimated soil ingestion rates for children residing on a Superfund site using a mass-balance methodology in which eight tracer elements (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) were analyzed. The methodology used in this study is similar to that employed in Calabrese *et al.* (1989). As in Calabrese *et al.* (1989), 64 children ages 1-3 years and predominantly from two-parent households were selected for this study. This stratified simple random sample of children was selected from the Anaconda, MT area. Thirty-six of the 64 children were male, and the children ranged in age from 1 to 3 years with approximately an equal number of children in each age group. The study was conducted for seven consecutive days during a two week period in the month of September. Duplicate samples of meals, beverages, and over- the-counter medicines and vitamins were collected over the seven day period, along with fecal samples. In addition, soil and dust samples were collected from the children's home and play areas. Toothpaste containing nondetectable levels of the tracer elements, with the exception of silica, was provided to all of the children. Infants were provided with baby cornstarch, diaper rash cream, and soap which were found to contain low levels of tracer elements.

As in Calabrese *et al.* (1989), an additional study was conducted in which the identical mass-balance methodology used to estimate soil ingestion rates among children was used on adults in order to validate that soil ingestion could be detected. Known amounts of soil were administered to ten adults (5 males, 5 females) from Western Massachusetts over a period of 28 days. Each adult ingested for 7 consecutive days: 1) no soil during Week 1, 2) 20 mg of sterilized soil during Week 2, 3) 100 mg of sterilized soil during Week 3, and 4) 500 mg of sterilized soil during Week 4. Soil samples were previously characterized and were of sufficient concentration to be detected in the analysis of fecal samples. Duplicate food and fecal samples were collected every day during each study week and analyzed for the eight tracer elements (Al, Si, Ti, Ce, La, Nd, Y, and Zr). The authors determined that a soil ingestion of 200 to 500 mg/day could be detected in a reliable manner.

Calabrese *et al.* (1997a) estimated soil ingestion by each tracer element using the Best Tracer Method (BTM), which allows for the selection of the most recoverable tracer for a particular group of subjects (Stanek and Calabrese, 1995b). In this case Ba, Mn, and V were dropped as they were found to be poor performing tracers. The median soil ingestion estimates for the four best trace elements based on food/soil ratios for the 64 children using Al, Si, Ti, Y, and Zr were presented (Table 5-2). The best estimate was calculated by taking the median of the best four trace elements. Based on the soil ingestion estimate for the best tracer, the mean soil ingestion rate was 66 mg/day and the median was 20 mg/day. The 95th percentile value was 283 mg/day. Using the median of the 4 best tracers, the mean was 7 mg/day and the 95th percentile was 160 mg/day. These results are lower than the soil ingestion estimates obtained by Stanek and Calabrese (1995a). Calabrese *et al.* (1997a) believe this may be due to the fact that the families of the children who participated in this study were aware that they lived on an EPA Superfund site and this knowledge might have resulted in reduced exposure. There was no statistically significant difference found in soil ingestion estimates by gender or age. There was also no significant difference in soil ingestion by housing or yard characteristics (i.e., porch, deck, door mat, etc.), or between children with or without pets.

The median dust ingestion estimates for the four best tracer elements using Al, Si, Ti, Y, and Zr were also presented (Table 5-3). The estimate is based on food/dust ratios for the 64 Anaconda children. The mean dust ingestion rate based on the best tracer was 127 mg/day and the 95th percentile rate was 614 mg/day.

The advantages of this study were the use of a longer 7 consecutive day study period rather than two periods of 3 and 4 days (Stanek and Calabrese, 1995a), the use of the BTM, the use of an expanded adult validation study which used 10 volunteers rather than 6 (Calabrese *et al.*, 1989), and the use of a dietary education program to reduce food tracer input and variability. However, the data presented in this study are from a single 7-day period during September which may not reflect soil ingestion rates for other months or time-periods. In addition, the study displayed a net residual negative error, which may have resulted in underestimated soil ingestion rates. The authors believe that this error is not likely to affect the median by more than 40 mg/day.

5.2.1.3 Davis and Mirick, 2006

Davis and Mirick (2006) calculated soil ingestion for children and adults in the same family using a mass balance approach. The families in this study were a subset of the 104 families who participated in the soil ingestion study by Davis *et al.* (1990), and the data were collected in 1988, one year prior to the Davis *et al.* study. Nineteen families were selected for the analyses in this study, and each consisted of a child participant between the age of 3 and 7, a female, and a male parent or guardian living in the same house. Samples were collected for 11 consecutive days of all food items consumed, all feces excreted, twice-daily urine, and soil/house dust. Tracer elements for this study included aluminum, silicon and titanium. In addition, parents completed a daily diary of activities for themselves and the participant child for 4 consecutive days during the study period.

Soil ingestion rates are shown for all three family member participants in Table 5-4. The mean and median estimates for children for all three tracers ranged from 36.7 to 206.9 mg/day and 26.4 to 46.7 mg/day, respectively, and fall within the range of those reported by Davis *et al.*, 1990. Adult soil ingestion estimates ranged from 23.2 to 624.9 mg/day for mean values and from 0 to 259.5 mg/day for median values, and were more variable than for the children in the study regardless of the tracer. The authors believed that this higher variability may have indicated an important occupational contribution of soil ingestion in some, but not all, of the adults. Similar to previous studies, the soil ingestion estimates were the highest for titanium. Although toothpaste is a known source of titanium, the titanium content of the toothpaste used by study participants was not determined.

Only three of a number of behaviors examined for their relationship to soil ingestion were found to be associated with increased soil ingestion in this study:

- reported eating of dirt (for children);
- occupational contact with soil (for adults); and
- hand washing before meals (for both children and adults).

Several typical childhood behaviors, however, including thumb-sucking, furniture licking, and carrying around a blanket or toy were not associated with increased soil ingestion for the participating children. Among both parents and children, neither nail-biting nor eating unwashed fruits or vegetables was correlated with increased soil ingestion. When investigating correlations within the same family, a child's soil ingestion was not found to be associated with either parent's soil ingestion, nor did the mother and father's soil ingestion appear to be correlated.

One advantage of this study is that it examines soil ingestion among family members, both children and adults. However, the sample population was small. In addition, the families were a subset of those in a previous study, chosen for their high compliance with the study protocol, and as such may not be representative of the general population.

5.2.2. Relevant Studies of Primary Analysis

5.2.2.1 Binder *et al.*, 1986

Binder *et al.* (1986) used a tracer technique modified from a method previously used to measure soil ingestion among grazing animals to study the ingestion of soil among children 1 to 3 years of age who wore diapers. 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 on the basis of each of the three tracer elements using a standard assumed fecal dry weight of 15 g/day, and the following equation:

$$T_{i,e} = \frac{f_{i,e} \times F_i}{s_{i,e}} \qquad (5\text{-}1)$$

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 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 5-5). 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 median values were 121 mg/day, 136 mg/day, and 618 mg/day for aluminum, silicon, and titanium, respectively. 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 they 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.

5.2.2.2 Clausing *et al.*, 1987

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, soil ingestion was estimated for each tracer. Eight daily fecal samples were also collected from six hospitalized, bedridden children. These children served as a control group, representing children who had 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 5-6). 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 on the assumption that the maximum amount of soil ingested cannot be higher than the lowest estimate for the individual tracers.

Mean (arithmetic) soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum (Table 5-7). 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).

The advantages of this study are that the investigators 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 that found in child care centers in The Netherlands and other European countries, compared to child care centers in the U.S.

5.2.2.3 Calabrese *et al.*, 1989

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 study, eight tracer elements—aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium— were analyzed instead of only three (aluminum, silicon, and titanium). Sixty-four children between the ages of 1 and 4 years old were included in the study. These children were all selected from the greater Amherst, MA area and were predominantly from two-parent households where the parents were highly educated. The Calabrese *et al.* (1989) study was conducted over a period of eight days to two weeks and included the use of a mass-balance methodology in which duplicate samples of food, beverages, medicines, and vitamins were collected and analyzed 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.

In order to validate the mass-balance methodology used to estimate soil ingestion rates among the children and to determine which tracer elements provided the most reliable data on soil ingestion, known amounts of soil (300 mg over 3 days and 1,500 mg over 3 days) containing eight tracers were administered to six adult volunteers (three males and three females). Soil, feces, and samples of food were analyzed for tracer elements to calculate recovery rates of tracer elements in soil. From this investigation the authors confirmed that the tracer methodology could adequately detect tracer elements in feces at the levels expected for the study of soil intake rates in children. Aluminum, silicon, and yttrium exhibited the lowest standard deviation of recovery and were therefore identified as the most reliable of the eight tracer elements analyzed; the percentage of recovery of these three tracers was closest to 100%. 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 5-8).

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 5-5). Median intake rates were somewhat lower (29 mg/day for aluminum, 40 mg/day for silicon, and 9 mg/day for yttrium). Upper (95^{th}) percentile 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 5-9). Intake of soil and dust was estimated using a weighted 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.

In a subsequent paper (Calabrese and Stanek, 1992a), the authors used statistical modeling to revise these soil ingestion estimates downward, based on a more accurate representation of the amount of outdoor soil in indoor dust (31.3%). These new analyses indicate that the estimates of median outdoor soil ingestion presented in the previous study should be reduced by 35%. These revised soil ingestion estimates are reduced from 29 to19 mg/d based on aluminum, 40 to 26 mg/d based on silicon, and 9 to 6 mg/d based on yttrium. However, this adjustment was not used in subsequent analyses by Stanek and Calabrese.

The advantage of this study is that intake rates were corrected for tracer concentrations in foods and medicines . 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 it may not be entirely representative of the U.S. population because it was selected from a single location. The results presented in Calabrese *et al.* 1989 have been superseded by more refined analyses of the same data.

5.2.2.4 Van Wïjnen *et al.*, 1990

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 acid insoluble residue (AIR)) in soil and feces and estimated soil ingestion based on the LTM. An average daily feces dry weight of 15 g 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.

The authors 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 5-10) 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 5-11). The authors 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. The major limitation of this study is that 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.

5.2.2.5 Calabrese *et al.* 1996

Calabrese *et al.*, 1996 examined the hypothesis that one cause of the variation between tracers seen in soil ingestion studies could be related to differences in soil tracer concentrations by particle size. In this study, the soil that was used by Calabrese et al. 1997a from Anaconda, Montana was reanalyzed for the tracer concentration after it had been sieved to a particle size of <250 μm in diameter (<2 mm soil particle size in the original study). The smaller particle size was examined based on the assumption that children and adults principally ingest soil of small particle size adhering to fingertips and under fingernails. For five of the tracers used in the original study (Al, Si, Ti, Y, and Zr), soil concentration was not changed by particle size. However, the soil concentrations of three tracers (La, Ce, and Nd) were increased two- to fourfold at the smaller soil particle size. Soil ingestion estimates for these three tracers were decreased by approximately 60% at the 95th percentile.

The importance of this study is that it provides further insights regarding the selection of tracers for soil ingestion studies.

5.2.2.6 Calabrese *et al.* 1999

Calabrese et al. 1999 extends the findings from Calabrese et al. 1996 by quantifying trace element concentrations in soil based on sieving to particle sizes of 100 to 250 μm and to particle sizes of 53 to < 100 µm. This study used the data from soil concentrations from the Anaconda, Montana site reported by Calabrese et al. 1997. Results of the study indicated that soil concentrations of Al, Si, and Ti do not increase at the two finer particle size ranges measured. However, soil concentrations of Ce, La, and Nd increased by a factor of 2.5 to 4.0 in the 100-250 µm particle size range when compared with the 0 to 2 µm particle size range. There was not a significant increase in concentration in the 53 to 100 µm particle size range.

The importance of this study is that it provides further insights regarding the selection of tracers for soil ingestion studies.

5.2.2.7 Stanek and Calabrese 2000

In Stanek and Calabrese, 2000, the authors reanalyzed the soil ingestion data from the Anaconda study. The authors assumed a lognormal distribution for the soil ingestion estimates in the Anaconda study to predict average soil ingestion for children over a longer time period. Using best linear unbiased predictors, the authors predicted 95th percentile soil ingestion values over time periods of 7 days, 30 days, 90 days, and 365 days. The 95th percentile soil ingestion values were predicted to be 133 mg/day over 7 days, 112 mg/day over 30 days, 108 mg/day over 90 days, and 106 mg/day over 365 days. Based on this analysis, estimates of the distribution of longer term average soil ingestion are expected to be narrower, with the 95th percentile estimates being as much as 25% lower (Stanek and Calabrese, 2000).

5.2.2.8 Stanek *et al.* 2001b

Stanek *et al.* (2001b) developed best linear unbiased predictors to reduce the biasing effect of short-term soil ingestion estimates. This study estimated long-term average soil ingestion distribution using daily soil ingestion estimates from children who participated in the Anaconda, MT study. In this long-term (annual) distribution, the soil ingestion estimates were: mean 31, median 24, 75th percentile 42, 90th percentile 75, and 95th percentile 91 mg/day. A limitation of this analysis is that the distribution of long-term soil ingestion uses the median soil ingestion estimate on a day, rather than the average of the tracer element estimate.

5.2.3 Key Studies of Secondary Analysis

5.2.3.1 Stanek and Calabrese, 1995a

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 a university 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 was 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. 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 5-12 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 5-13 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 5-13). 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 screening of data to remove less consistent tracer estimates, and the aggregation of the remaining values, may introduce error to the analysis. 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 5-12, are substantially more reliable than any available distributional estimates.

5.2.3.2 Stanek and Calabrese, 1995b

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 children, the authors 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 for children was estimated to be 104 mg/day (mean); 37 mg/day (median); and 217 mg/day (95th percentile), using the BTM.

When the adult data from the Calabrese *et al.* (1990) study were reevaluated, soil ingestion rates were estimated to be 64 mg/day (mean); 87 mg/day (median); and 142 mg/day (95th percentile), using the BTM.

This study provides a reevaluation of previous studies. Its advantages are that it combines data from two studies for children, one from Washington 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.

5.2.4. Relevant Studies of Secondary Analysis

5.2.4.1 Thompson and Burmaster, 1991

Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the key study data collected by Binder *et al.* (1986). In the original Binder *et al.* (1986) study, an assumed 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 5-11 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. 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 5-14 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. This analysis is based on a study that did not correct 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.

5.2.4.2 Calabrese and Stanek 1992a

Calabrese and Stanek 1992a estimated the amount of outdoor soil in indoor dust using statistical modeling. The model used data from 60 homes who participated in the Calabrese *et al.* 1989 study. Scatter plots of each tracer concentration in soil versus dust for the subject population were developed. Correlation analysis of the scatter plots was performed and an estimate of the proportion of outdoor soil in indoor dust was developed using a model based on the soil and dust data from Calabrese *et al.* 1989. The scatter plots show little evidence of a consistent relationship between outdoor soil and indoor dust concentrations. The model uses several simplifying assumptions. First, it assumes that the amount of dust produced every day from both indoor and outdoor sources in a house is constant for all houses. Second, the model assumes that the proportion of indoor dust due to outdoor soil is constant for all houses. Third, it assumes that the concentration of the tracer element in dust produced from indoor sources is constant for all houses. Using these assumptions, the model predicts that 31.3% of indoor dust comes from outdoor soil. This model was then used to adjust the soil ingestion estimates from Calabrese *et al.* 1989. In 1989, Calabrese assumed that all the excess fecal tracers were of soil origin. Stanek and Calabrese 1992a reported that 50% of the excess fecal tracers were from indoor origin. Taking that 50% multiplied by 31.3% results in 15%; which added to the 50%

indicates that approximately 65% of the total residual excess fecal tracer were of soil origin (Calabrese and Stanek 1992a).

This study provides a refinement to the calculations from Calabrese *et al.* 1989. However, several assumptions were made to estimate the total residual excess fecal tracer that comes from soil. The validity of these assumptions cannot be evaluated. Subsequent papers by Stanek and Calabrese did not make use of this adjustment.

5.2.4.3 Sedman and Mahmood , 1994

Sedman and Mahmood (1994) used the results of two previous children's tracer studies (Calabrese *et al.* 1989; Davis *et al.* 1990) 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. The authors determined soil ingestion in these children using a mass balance approach, 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. They 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:

$$\mathrm{Y_i} = xe^{-0.112 \times yr} \tag{5-3}$$

where:

$\mathrm{Y_i}$ = adjusted mean soil ingestion (mg/day)
x = a constant
yr = average age (2 years)

The average ages of children in the two previous 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. 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. 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.

5.2.4.4 Calabrese and Stanek, 1995

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:

- Ingestion of high levels of tracers before the start of the study and low ingestion during the 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 that 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) a 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; and (4) negative errors due to missing fecal samples at the end of the study period were also 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.

Table 5-16 presents the estimated magnitude of positive and negative error for six tracer elements in the children's study (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 5-15). 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 5-16). 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 study 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. The authors did not specifically identify sources of error or seek direct evidence that individual tracers were indeed in error. Corrections to individual tracer means were 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.

5.2.4.5 Stanek *et al.*, 2001a

In order to identify and evaluate biasing factors for soil ingestion estimates, the authors developed a simulation model based on data from previous soil ingestion studies. The soil ingestion data used in this model were taken from Calabrese *et al.*, 1989 (the Amherst study); Davis *et al.*, 1990; Calabrese *et al.*, 1997a (the Anaconda study) and Calabrese *et al.*, 1997b, and relied only on the aluminum and silicon trace element estimates provided in these studies.

Of the biasing factors explored, the impact of study duration was the most striking, with a positive bias of more than 100% for 95th percentile estimates in a 4-day mass balance study. A smaller bias was observed for the impact of absorption of trace elements from food. Although the trace elements selected for use in mass balance studies are believed to have low absorption, whatever amount is not accounted for will result in an underestimation of the soil ingestion distribution. In these simulations, the absorption of trace elements from food of up to 30% was shown to negatively bias the estimated soil ingestion distribution by less than 20 mg/day. No biasing effect was found for misidentifying play areas for soil sampling (i.e., ingested soil from a yard other than the subject's yard).

5.2.4.6 Zartarian *et al.*, 2005

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates from several studies in the literature to be used as input for the Stochastic Human Exposure and Dose Simulation (SHEDS) model which was used in the EPA report entitled *A Probabilistic Exposure Assessment for Children Who Contact CCA-Treated Playsets and Decks* (U.S. EPA 2005). Soil ingestion rate estimates were derived for the SHEDS-Wood model (this refers to the application of the SHEDS model to wood preservative exposure scenarios) using data from Calabrese's Amherst and Anaconda studies. Data statistics from both of these studies were used to fit distributions of soil/dust ingestion rates. The statistical distributions generated for variability and uncertainty distributions relied upon two tracers only, Al and Si, in estimating the parameters of the lognormal variability and uncertainty distributions. Using Monte-Carlo sampling, values from the fitted distribution were sampled. The sampled values were separated into those values under 500 mg/day and values that exceeded 500 mg/day. The model assumes that soil ingestion values that exceed 500 mg/day are representative of pica behavior. The soil ingestion rate distribution for non-pica behavior children developed for the SHEDS model has a mean of 61, standard deviation 81, median 30, 25th percentile 12, 75th percentile 73, 95th percentile 236, and 99th percentile 402 (mg/day). This distribution was simulated using only the results generated below 500 mg/day. For children exhibiting pica behavior the summary statistics are: mean 962 mg/day, standard deviation 758, median 735, 25th percentile 590, 75th percentile 1046, 95th percentile 2130, 99th percentile 3852 mg/day.

The strength of this analysis is that it provides variability and uncertainty distributions. It also provides estimates for pica behavior. A limitation of this analysis is that pica children and incidental ingestion were simulated separately. The distribution for incidental soil ingestion does not take into account that for long-term behavior, children are expected to have days where they may ingest unusually high levels of soil.

5.3 PICA

5.3.1. Prevalence

5.3.1.1 General Pica

Feldman (1986) defines pica as "the repeated eating of non-nutritive substances" . 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 pica behavior occurs in approximately half of all children between the ages of 1 and 3 years (Sayetta, 1986). The incidence of behavior ingesting non-nutritive substances 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 pica behavior, compared with 10 to 18 percent of white children in the same age group (Danford, 1982). There do 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). Pica 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, pica 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).

5.3.1.2 Soil Pica

It should be noted that the pica statistics cited above apply to the incidence of general pica and not *soil* pica. A soil pica workshop conducted by ATSDR defined soil pica as the recurrent ingestion of unusually high amounts of soil (i.e., 1,000 - 5,000 mg/day)(ATSDR, 2001). Information on the incidence of soil pica is limited, but it appears that soil pica is less common than general pica. In addition, parental observations regarding children who are likely to be high soil ingesters have been found to be inaccurate (Calabrese *et al.*, 1997b). A study by

Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., intentional earth-eating) was about 16 percent among children from a rural black community in Mississippi. However, geophagy 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 the recurrent ingestion of unusually high amounts of soil in the general population is low. However, it is incumbent upon the user to use the appropriate value for their specific study population.

5.3.2. Soil Pica Among Children

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

5.3.2.1. Calabrese *et al.*, 1991

Calabrese *et al.* (1991) estimated that upper range soil ingestion values may range from approximately 5 to 7 g/day. This estimate was based on observation 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 to 2200 mg/day during the first week of observation and from 10,100 to 13,600 mg/day during the second week of observation (Table 5-16). These results are based on mass-balance analyses for seven tracer elements (aluminum, barium, manganese, silicon, titanium, vanadium, and yttrium) of the eight used. Intake rates based on zirconium were significantly lower. In a subsequent paper, the authors indicated that this may have resulted from sample loss due to GI absorption (Stanek and Calabrese, 1994).

5.3.2.2. Calabrese and Stanek, 1992b

Using a methodology that compared differential element ratios, Calabrese and Stanek (1992b) quantitatively distinguished outdoor soil ingestion from indoor dust ingestion in a soil pica child. This study was based on a previous mass-balance study (Calabrese *et al.*, 1991) in which a 3.5-year-old child ingested 10 to 13 grams of soil per day during the second week of a 2-week soil ingestion study.

Table 5-17 presents tracer ratios of soil, dust, and residual fecal samples in the soil pica child. The authors 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 5-17. Of these 19 pairs, nine fecal tracer ratios fell between the limits for soil and dust (Table 5-17). For these nine tracer soils, an interpolation was performed to estimate the relative contribution of soil and dust to the residual fecal tracer ratio; this analysis indicates that from 71 to 99% of the tracer originated from soil. All of the other 10 fecal tracer ratios that fell outside the soil and dust limits were indicative of 100% soil origin. Therefore, the authors conclude that the predominant proportion of the fecal tracers originated from outdoor soil and not indoor dust.

5.3.2.3. Calabrese and Stanek, 1993

Calabrese and Stanek (1993) reviewed a study by Wong (1988) that attempted to estimate the amount of soil ingested by two groups of children. Wong studied a total of 52 children in two government institutions in Jamaica. The younger group (from the Glenhope Place of Safety) contained 24 children with an average age of 3.1 years (range of 0.3 to 7.6 years). The older group (from the Reddies Place of Safety) contained 28 children with an average age of 7.2 years (range of 1.8 to 14 years). Fecal samples were obtained from the subject children and the amount of silicon in dry feces was measured to estimate soil ingestion.

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

The amount of soil ingested was calculated using the formula of Binder *et al.* (1986). One fecal sample was collected each month from each subject over the four-month study period.

For the 28 children in the older group, soil ingestion was estimated to be 58 mg/day, based on the mean minus one outlier, and 1520 mg/day, based on the mean of all the children. The outlier was a child with an estimated average soil ingestion rate of 41 g/day over the 4 months. Of the 28 children in the group, 7 had an average soil ingestion greater than 100 mg/day, 4 had an average soil ingestion greater than 200 mg/day, and 1 had an average soil ingestion greater than 300 mg/day; 8 children showed no indication of soil ingestion.

Estimates of soil ingestion were higher in the younger group of children. The mean soil ingestion of all the children was 470 ± 370 mg/day. Due to some sample losses, of the 24 children studied, only 15 had samples for each of the 4 months of the study. Of the 24 children in the group, 14 had an average soil ingestion less than 100 mg/day, 10 had an average soil ingestion greater than 100 mg/day, 5 had an average soil ingestion greater than 600 mg/day, and 4 had an average soil ingestion greater than 1000 mg/day; 5 children showed no indication of soil ingestion.

Over the entire 4-month study period, 9 of 84 samples (or 10.5%) yielded soil ingestion estimates in excess of 1 g/day, indicating pica behavior. Of the 52 children studied, 6 displayed soil pica behavior. The estimated soil ingestion for each of these subjects is shown in Table 5-18. For the younger group of children, 5 of 24 (or 20.8%) displayed pica behavior on at least one occasion. A high degree of daily variability in soil ingestion was observed among the six pica children; three (#11, 12, and 22) showed pica behavior on only 1 of 4 days. The other three (#14, 18, and 27) showed pica behavior on 2, 3, and 4 days, respectively. Subject #27 consumed the most soil (3.7 to 60.6 g/day); however, it was indicated that this child was mentally retarded, whereas the other pica children were considered to have normal mental capabilities.

Sources of uncertainty or error in this study include differences between the hospital study group (the background control) and the two study groups, lack of information on the intake of silicon for the children in the study, use of a single fecal sample, and loss of fecal samples. The use of a single soil tracer may also introduce error because there may be other sources of the tracer in the children's environment. For example, some toothpastes have extremely high silica concentrations, and children may ingest significant quantities of toothpaste. Tracers may also be found in indoor dust that children could ingest. However, despite these uncertainties, the results are important in that they indicate that soil pica is not a rare occurrence in younger children.

5.3.2.4. Zartarian *et al.* 2005

Zartarian *et al.* (2005) conducted an analysis of soil ingestion rates from several studies in the literature to be used as input for the Stochastic Human Exposure and Dose Simulation (SHEDS-Wood) model which was used in the EPA report entitled *A Probabilistic Exposure Assessment for Children Who Contact CCA-Treated Playsets and Decks* (U.S. EPA 2005). Soil ingestion rate estimates were derived for the SHEDS-Wood model using data from Calabrese's Amherst and Anaconda studies. Data statistics from both of these studies were used to fit distributions of soil/dust ingestion rates. Zartarian et al. (2005) derived a soil pica distribution by sampling from the fitted lognormal distribution and retaining values above 500 mg/day. The mean and 95th percentile values for this population was estimated to be 963 mg/day and 2170 mg/day, respectively. The distribution is presented in Table 5-20.

5.4 RECOMMENDATIONS

The key studies described in this section were used to recommend values for soil intake among children. The list of these studies is provided in Table 5-19. Estimates of the amount of soil ingested by children based on the key studies are summarized in Table 5-20 and the recommended values are presented in Table 5-21. The mean values ranged from 38 mg/day to 193 mg/day with a weighted average of 90 mg/day for soil ingestion and 106 mg/day when it was considered that a portion of the soil ingested comes from dust. These estimates are based on weighted averages using aluminum and silicon as tracers, except for Calabrese *et al.* (1997), which uses the best tracer methodology. These tracer elements were considered the most reliable based on a review of the current literature. Results obtained using titanium as a tracer were not considered in the derivation of the recommendations because titanium exhibits greater variability compared to other tracers. Results using titanium are consistently higher than other tracers. This may indicate that there are other non-food and non-soil sources of titanium being ingested. For example, titanium is used in paper coatings and as paper fillers and in paints, lacquers, and enamels (IPCS, 1982). Ingestion of these non-food items has not been investigated.

Most of the studies used in this chapter did not categorize soil intake by the age groups recommended in EPA 2005. Therefore, the recommended values in Table 5-21 apply to children from age 1 to 7 years. At this time, the raw data from these studies are not available. Data are particularly lacking for children < 1 year of age. Van Wijnen *et al.* (1990) (Table 5-10) derived soil ingestion estimates for various age categories. Although Van Wijnen *et al.* (1990) was not considered a key study because the presence of tracers in food and medicines was not taken into consideration and the study may not representative of U.S. children, it showed that children 4 to < 5 years of age had median soil ingestion rates up to 1.8 times higher than children <1 year of age. However, one needs to consider that infants may spend most of their time indoors and dust concentration may be more appropriate for calculating ingestion rates for this group. Using dust concentrations for estimating intake rates generally results in higher ingestion rates. Dust samples were not collected by Van Wijnen *et al.* (1990).

There are a number of limitations with the data presented in Table 5-20. A number of studies have indicated that aluminum and silicon can be absorbed in small amounts from the digestive tract in adults (Davis and Mirick 2006). Therefore, these soil ingestion values may be biased low. It is also worth noting that even though there are five key studies presented in Table 5-20, they represent only four populations (i.e, Amherst, Anaconda, Tri-city area in southeastern Washington, and a subset of the Tri-city area study) adding up to 241 children. Other studies are reanalyses of these populations. Therefore, in some instances the same population is counted more than once in the weighted averages presented in Table 5-20. In addition, since the children were studied for short periods of time and the prevalence of pica behavior is not known, excluding children with pica behavior from the calculations may underestimate long-term soil intake rates. It is plausible that many children may exhibit some pica behavior if studied for longer periods of time. Since young children may spend a significant number of hours indoors, it may not be appropriate to assume that all the soil ingested came from outdoor exposure. Therefore, the recommended soil ingestion values are based on soil and dust estimates. Rounding up to the nearest hundred, **100 mg/day is the best estimate of the mean soil ingestion for children under 7 years of age.** Over the period of study, 95th percentile values ranged from 217 mg/day to 449mg/day with an average of 236 mg/day for soil ingestion and 449 mg/day when both soil and dust are considered. **Rounding to the nearest hundred, the recommended 95th percentile soil ingestion rate for children is 400 mg/day based on soil and dust ingestion.** A distribution of soil ingestion values is presented in Table 5-20. However, since the children were studied for a short period of time and usually during the summer months, these values are not estimates of usual intake.

Data on soil ingestion rates for children who exhibit pica behavior (i.e., ingest unusually high amounts of soil on a recurrent basis) are also limited. In conducting a risk assessment for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) also investigated the potential for exposure to 2,3,7,8-TCDD via soil ingestion. CDC used a value of 10 g/day to represent the amount of soil that a child with pica behavior might ingest (Kimbrough *et al.*, 1984). These values are consistent with those observed by Calabrese *et al.* (1991). An ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information. This value is based on only one pica child observed in the Calabrese *et al.* (1989) study where the intake ranged from 10-14 grams/day during the second week of observation. In addition, a statistical designation is not assigned to this value.

These recommendations are based on studies that used different survey designs and populations. For example, in some studies soil ingestion estimates were adjusted to account for the contribution of house dust to this estimate. Other studies used best tracer methodology while others relied on estimates from specific tracers. 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 5-22. It is important to understand, however, 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 non food 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 parents' 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 in this section are derived from studies which were mostly conducted in the summer, exposure during the winter months, when the ground is frozen or snow covered in many regions of the United States, 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 house dust comes from outdoor soil.

5.5 REFERENCES FOR CHAPTER 5

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Table 5-1. 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 5-2. Soil Ingestion Estimates for the Median of Best Four Trace Elements Based on Food/Soil Ratios for 64 Anaconda Children (mg/day) Using Al, Si, Ti, Y, and Zr

Category	Soil Ingestion (mg/day)[a]										
	Min	P5	P10	P25	P50	P75	P90	P95	Max	Mean	SD
Median of best 4	-101.3	-91.0	-53.8	-38.0	-2.4	26.8	73.1	159.8	380.2	6.8	74.5
Best tracer	-53.4	-24.4	-14.4	2.2	20.1	68.9	223.6	282.4	609.9	65.5	120.3
2nd best	-115.9	-62.1	-48.6	-26.6	1.5	38.4	119.5	262.3	928.5	33.2	144.8
3rd best	-170.5	-88.9	-67.0	-52.0	-18.8	25.6	154.7	376.1	1293.5	31.2	199.6
4th best	-298.3	-171.0	-131.9	-74.7	-29.3	0.2	74.8	116.8	139.1	-34.6	79.7

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

Source: Calabrese *et al.* (1997).

Table 5-3. Dust Ingestion Estimates for the Median of Best Four Trace Elements Based on Food/Dust Ratios for 64 Anaconda Children (mg/day) Using Al, Si, Ti, Y, and Zr

Category	Soil Ingestion (mg/day)[a]										
	Min	P5	P10	P25	P50	P75	P90	P95	Max	Mean	SD
Median of best 4	-261.5	-186.2	-152.7	-69.5	-5.5	62.8	209.2	353.0	683.9	16.5	160.9
Best tracer	-377.0	-193.8	-91.0	-20.8	26.8	198.1	558.6	613.6	1499.4	127.2	299.1
2nd best	-239.8	-147.2	-137.1	-59.1	7.6	153.1	356.4	409.5	1685.1	82.7	283.6
3rd best	-375.7	-247.5	-203.1	-81.7	-14.4	49.4	406.5	500.5	913.2	25.5	235.9
4th best	-542.7	-365.6	-277.7	-161.5	-55.1	52.4	277.3	248.8	6120.5	81.8	840.3

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

Source: Calabrese *et al.* (1997).

Table 5-4. Mean and Median Soil Ingestion (mg/day) by Family Member

Participant	Tracer Element	Estimated Soil Ingestion[a] (mg/day)			
		Mean	Median	Std	Maximum
Child[b]	Aluminum	36.7	33.3	35.4	107.9
	Silicon	38.1	26.4	31.4	95.0
	Titanium	206.9	46.7	277.5	808.3

Source: Davis and Mirick 2006

[a] For some study participants, estimated soil ingestion resulted in a negative value. These estimates have been set to 0 mg/day for tabulation and analysis.

[b] Results based on 12 children with complete food, excreta, and soil data.

Table 5-5. 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	578	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 5-6. 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 5-7. 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 5-8. Mean and Standard Deviation Percentage Recovery of Eight Tracer Elements

Tracer Element	300 mg Soil Ingested		1,500 mg Soil Ingested	
	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 5-9. Soil and Dust Ingestion Estimates for Children Ages 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 5-10. 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)
birth to <1	Girls	3	81	1.09	-	-	-
	Boys	1	75	-	-	-	-
1 to <2	Girls	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2 to <3	Girls	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3 to <4	Girls	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4 to <5	Girls	1	180	-	19	164	1.48
	Boys	4	99	1.62	18	136	1.30
3 to <5[c]	Girls	27	146	1.57	25	164	1.38
	Boys	33	105	1.47	26	142	1.36
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.

[c]This age category is calculated from the previous two rows of data in order to conform to the standardized age categories used in this Handbook.

Source: Adapted from Van Wijnen *et al.* (1990).

Table 5-11. Estimated Geometric Mean Limiting Tracer Method (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 to <2	18	103	33	80
	2 to <3	33	109	48	91
	4 to <5	5	124	6	109
Reasonable	<1			1	61
(2-3 days/week precipitation)	1 to <2			10	96
	2 to <3			13	99
	3 to <4			19	94
	4 to <5			1	61
	3 to <5[a]			20	92
Good	<1	4	102		
(<2 days/week precipitation)	1 to <2	42	229		
	2 to <3	65	166		
	3 to <4	67	138		
	4 to <5	10	132		
	3 to <5[a]	77	137		

[a]This age category is calculated from the available data in order to conform to the standardized age categories used in this Handbook. Value is a weighted mean of the previous two rows.

Source: Van Wijnen *et al.* (1990).

Table 5-12. 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 5-13. 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 5-14. Summary Statistics and Parameters for Distributions of Estimated Soil Ingestion by Tracer Element[a]

	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] Using Binder *et al.* (1986) data with actual fecal weights.

[b] Mean = arithmetic average of soil ingestion based on aluminum and silicon.

Source: Thompson and Burmaster (1991).

Table 5-15. 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]

Tracer	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 5-16. Daily Soil Ingestion Estimation in a Soil-Pica Child by Tracer and by Week (mg/day)

Tracer element	Estimated Soil Ingestion (mg/day)	
	Week 1	Week 2
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 5-17. Ratios of Soil, Dust, and Residual Fecal Samples in the Soil Pica Child

Tracer Pairs	Ratio			Estimated Residual Fecal Tracers of Soil Origin as Predicted by Specific Tracer Ratios (%)
	Soil	Fecal	Dust	
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 5-18. Daily Variation of Soil Ingestion by Children Displaying Soil Pica in Wong (1988)

Child subject number	Month	Estimated soil ingestion (mg/day)
Glenhope Place of Safety		
11	1	55
	2	1,447
	3	22
	4	40
12	1	0
	2	0
	3	7,924
	4	192
14	1	1,016
	2	464
	3	2,690
	4	898
18	1	30
	2	10,343
	3	4,222
	4	1,404
22	1	0
	2	--
	3	5,341
	4	0
Reddies Place of Safety		
27	1	48,314
	2	60,692
	3	51,422
	4	3,782

Source: Calabrese and Stanek (1993).

Table 5-19 Key Studies Used to Derive Recommendations

Key Studies	Sample Size	Comments
Davis *et al.* 1990	101	Primary analysis
Stanek and Calabrese, 1995a	64	Secondary analysis. This paper is a refinement of the data collected by Calabrese *et al.* 1989
Stanek and Calabrese, 1995b	162	Secondary analysis. This paper is a refinement of the data collected by Calabrese *et al.* 1989 and Davis *et al.* 1990 using the best tracer methodology.
Calabrese *et al.* 1997a	64	Primary analysis
Davis and Mirick 2006	12	Primary Analysis

Table 5- 20 . Summary of Estimates of Incidental Soil and Dust Ingestion by Children (1-7 years old) from Key Studies (mg/day)[a]

Sample Size	Age (yr)	Source	Mean	P25	P50	P75	P90	P95	Reference
101	2-7	Soil	61		42				Davis *et al.* 1990
		Soil and Dust	112		82				
64	1-4	Soil	131	8	31	84	169	239	Stanek and Calabrese 1995a
162	1-7	Soil	104	10	37	80	156	217	Stanek and Calabrese 1995b
64 [b]	1-3	Soil	66	2	20	69	224	283	Calabrese *et al.* 1997a
		Dust Only [c]	127	-	27	198	559	614	
		Soil and Dust [d]	97		24	134	392	449	
12	3-7	Soil	38						Davis and Mirick 2006
Weighted Average	1-7	Soil	90	8	35	78	174	236	
		Soil and Dust	106		60	134	392	449	

[a] Using the average of Al and Si as tracers (except otherwise specified under note “b”)

[b] Using the best tracer method

[c] Calculated assuming all the ingestion originated from dust.

[d] Calculated by averaging the “soil” and “dust only” rows.

Table 5-21. Summary of Recommended Values for Soil Ingestion

Population	Mean		95th percentile	
Children (1-7 years old)	Incidental Ingestion	Pica	Incidental Ingestion	Pica
	100 mg/day	10 g/day	400 mg/day	--

Note: See Section 5.4 for discussion of these values.

Table 5-22. Confidence in Soil Intake Recommendation

Considerations	Rationale	Rating
Study Elements		
C Level of peer review	All key studies are from peer review literature.	High
C Accessibility	Papers are widely available from peer review journals. However, raw data were not available to do age specific analysis	Medium
C Reproducibility	Methodology used was presented, but results are difficult to reproduce.	Medium
C Focus on factor of interest	The focus of the studies was on estimating soil intake rate by children.	High
C Data pertinent to U.S.	Studies used children from specific areas of the U.S.	Medium
C Primary data	All the studies were based on primary data.	High
C Currency	Studies were conducted after 1980. Soil ingestion behaviors are not expected to change with time.	High
C Adequacy of data collection period	Children were not studied long enough to fully characterize day to day variability. Most of the studies were conducted during the summer months.	Medium
C 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
C Study size	The sample sizes used in the key studies were adequate for some age groups, but not representative of the U.S. Data are lacking for the very young children and children older than 7 years old.	Medium
C 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.	Low
C Characterization of variability	Day-to-day variability was not very well characterized.	Low
C 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).	Low
C Measurement error	Errors may result due to problems with absorption of the tracers in the body and mismatching inputs and outputs.	Low
Other Elements		

Table 5-22. Confidence in Soil Intake Recommendation

Considerations	Rationale	Rating
C Number of studies	There are 5 key studies. However, only four of those are original data.	Medium
C 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 some age groups; accuracy of methodology is uncertain; variability cannot be characterized due to limitations in data collection period. Data at the upper end are highly uncertain. Distributions provided may not be representative of long-term behavior.	**Medium** (for children - long-term central estimate) **Low** (for upper percentile and distributions of long-term behavior)