2. ESTIMATING EXPOSURES AND RISKS

2.1. INTRODUCTION

In this chapter, the framework for assessing exposure and risk to 2,3,7,8-TCDD and related dioxin-like compounds will be described. Section 2.2 introduces the exposure equation and its key terms. Section 2.3 describes how cancer risk and non-cancer risk estimates are generated, given exposure estimates. Section 2.4 summarizes procedures for calculating exposure and risk for dioxin toxic equivalents. Section 2.5 provides the overview of the procedures used in this document. Section 2.6 describes the development of exposure scenarios for this assessment. Finally, Section 2.7 discusses the exposure pathways and exposure parameters chosen for this assessment.

The development of exposure assessment methods, scenarios and associated parameter values raises many issues which are generic to all chemicals. In order to keep the scope of this document reasonable, the decision was made to focus on issues specific to dioxin-like compounds and to avoid evaluating generic issues. Thus, priority is given to addressing issues such as fish bioconcentration, dermal absorption, degradation, and other chemical/physical properties of these compounds. The approach used to address generic issues such as soil ingestion rates, inhalation rates and other behavior parameters is based on published Agency documents, primarily the Exposure Factors Handbook, published first in 1989 (EPA, 1989). The current version of the Exposure Factors Handbook was published in 1997 (EPA, 1997a). Exposure factors used in this chapter are based on this version.

Another generic issue which has been raised in connection with this document is the use of Monte Carlo procedures to define exposure scenarios. These procedures require distributions for the input parameters used in the assessment. Such distributions are now being addressed in the Exposure Factors Handbook. However, this document has not demonstrated Monte Carlo and related procedures on the scenarios developed in this chapter. Individuals outside of the Agency have published assessments which applied Monte Carlo procedures to problems involving dioxin-like compounds. In recognition of the high interest in this area, a general description of this technique and summaries of assessments which applied it to dioxin-like compounds are included in Chapter 8 of this Volume.

2.2. EXPOSURE EQUATION

This document describes procedures for conducting exposure assessments to estimate either potential or internal dose. A potential dose is defined as a daily amount of contaminant inhaled, ingested, or otherwise coming in contact with outer surfaces of the body, averaged over an individual's body weight. An internal dose is defined as the amount of the potential dose which is absorbed into the body. Section 2.3 below discusses the relevancy of this distinction for dioxin-like compounds.

The general equation used to estimate potential dose normalized over body weight and lifetime is as follows:

Lifetime Average Daily Dose (LADD) = (exposure media concentration x contact rate x contact fraction x exposure duration) / (body weight x lifetime) (2-1)

The LADD is used to assess cancer risks. Non-cancer risks from exposure to dioxin-like compounds can be assessed using the Average Daily Dose, or ADD. This is calculated as in Equation (2-1), but without the exposure duration in the numerator and the lifetime in the denominator. Each of the terms in this exposure equation is discussed briefly below:

- **Exposure media concentrations:** These include the concentrations in soil for the dermal contact and soil ingestion exposure pathways, in the vapor and particulate phases in air for the inhalation exposure pathway, in water for the water ingestion pathway, and in food products such as fish, fruits and vegetables, and beef and milk, for the food ingestion pathways. The concentrations used should represent an average over the exposure period. Chapter 4 provides models for estimating exposure media concentrations.
- **Contact rate:** These include the ingestion rates, inhalation rates, and soil contact rates for the exposure pathways. These quantities are generally the total amount of food ingested, air inhaled, etc. Only a portion of this material may be contaminated. The next term, the contact fraction, which is 1.0 or less, reduces the total contact rate to the rate specific to the contaminated media.
- **Contact fraction:** As noted, this term describes the distribution of total contact between contaminated and uncontaminated media. For example, a contact fraction of 0.8 for inhalation means that 80% of the air inhaled over the exposure period contains dioxin-like compounds in vapor form or sorbed to air-borne particulates. The contact fractions for the exposure pathways of air inhalation and water ingestion are related to the time individuals spend at home. Other pathways such as fish ingestion or ingestion of home grown foods are not related to time at home. Similarly, contact fractions for individuals exposed at work places relate

largely to time spent at the work place. EPA (1997a) discusses several time use studies which can be used to make assumptions about time spent at home (and outdoors at the home environment) versus time spent away from home. Generally, these time use studies asked participants to keep 24 hour diaries of all activities. Studies summarized were national in scope, involved large numbers of individuals, cross-sections of populations in terms of age and other factors, and up to 87 categories of activities. Results from different studies reviewed in EPA (1997a) consistently indicate that the average adult spends between 68 to 73% of time at the home environment.

- **Exposure duration:** This is the overall time period of exposure. Values of 9 years and 30 years are used in the example scenarios described in Chapter 5. EPA (1997a) describes several population mobility studies. A recent study by the U.S. Bureau of the Census (1993) covered a national sample of 55,000 interviews. The 50th and 90th percentile values of values for years living in current residence were determined to be 9.1 and 32.7 years, which are rounded here simply to 9 and 30 years. The 9 years will be used in a residential scenario and the 30 years for the farming scenario. The fact that farmers tend to live longer in their residents than average individuals was supported by a second study (Isreali and Nelson,1992) described in EPA (1997a) which categorized respondents in a number of different ways. The average time living in current residence for individuals in farms was 17.3 years, while it was 7.8 years for individuals in rural settings and 4.6 years for all households (Isreali and Nelson,1992). Another exposure duration demonstrated in Chapter 5 is one associated with a childhood pattern of soil ingestion. The exposure duration in this case is 5 years.
- **Body weight:** The human adult body weight of 70 kg is assumed. While the average adult (males and females) body weight is closer to 60 kg (EPA, 1997a), 70 kg has been traditionally used by the Agency and will be used in this assessment where appropriate. This document has chosen to use consumption rate data that are in terms of g food consumed/kg body weight/day, rather than g food consumed/day. Therefore, body weight drops out as an exposure factor for these pathways; it is still required in this assessment for the inhalation, soil ingestion, soil dermal contact, and the water ingestion pathways. The fish consumption pathway still uses the g/day convention since most fish consumption survey data, and the data used in this assessment, are in that form. As such, this pathway also

uses the 70 kg body weight assumption. The average of male and female average body weights at ages 1 through 6 was 16.6 (EPA, 1997a). This was used to assume an average body weight of 17 kg for the childhood pattern of soil ingestion. The 70 kg adult body weight will be used in some, but not all of the pathways.

- **Lifetime:** Following traditional assumptions, the average adult lifetime assumed throughout this document is 70 years. Even though actuarial data indicate that the United States average lifetime now exceeds 70 years, this convention is used to be consistent with other Agency assessments of exposure and risk.

2.3. CANCER AND NON-CANCER RISK ASSESSMENT

The primary source of information on the health risks of the dioxin-related compounds is the Health Document of this Reassessment, Part II of the Reassessment Documents (Part I are the Exposure Documents and Part III is the Risk Characterization). While that remains the principal source of information on potential health effects resulting from dioxin exposures, some general procedures for using exposure estimates in support of cancer and non-cancer risk assessments are summarized here.

The Risk Characterization emphasizes that risk assessments for dioxin-like compounds must consider background exposures when evaluating the impact of increments that are due to specific sources:

> *When evaluating incremental exposures associated with specific sources, knowing the increment relative to background may help to understand the impact of the incremental exposure. For instance, it would be misleading to focus on incremental exposure in evaluating the potential impact on human health when a relatively large background body burden of dioxin already exists in the exposed population. In these circumstances, the incremental exposure needs to be evaluated in the context of these background levels. This has led us to suggest that perhaps the best information for a decision-maker to have is: (1) a characterization of effects noted in the low dose range; (2) a characterization of the range and average of "background" exposures, including a discussion of MOE; (3) a characterization of the incremental percent increase over background of individuals or subpopulations of interest; and (4) guidance on when contributions from incremental exposures adding to average "background" become significant for the decision.*

The Risk Characterization as well as the Health Document provide detailed discussions of the effects of dioxin exposure in the low dose, or background, range, and those discussions are not repeated here. These documents also discuss in great deal the Margin Of Exposure, MOE, concept and the MOE associated with current background exposures. The MOE is calculated by dividing a "point of departure" dose or exposure at the low end of the range of observation in human or animal studies by the comparable surrogate of human exposure at a "level of interest". These points of departure could include the human-equivalent lowest observed adverse effect level (LOAEL), the no observed adverse effect level (NOAEL), the benchmark dose (BMD), or the effective dose (ED) at some percentage; ED_{01} is the effective dose for 1% of the population. Points of departure could also be body burden levels associated with health effects. The comparable "level of interest" for dioxin-like compounds are defined here as terms relating to background exposures, or perhaps, background exposures plus incremental exposures due to a specific source being evaluated. The Risk Characterization provides this general guidance regarding interpretation of MOEs:

> *Generally speaking, when considering either background exposures or incremental exposures plus background, MOEs of 100 or more are considered adequate to rule out the likelihood of significant effects occurring in humans based on sensitive animal responses or results from epidemiologic studies and traditional factors used in safety assessment. Conversely, as MOEs approach the range of observation of effects, reaching any conclusion regarding the certainty of no harm is much more difficult.*

The Risk Characterization concludes that the MOE for background exposures are well below 100 and even below 10:

> *One of the difficulties in assessing the potential health risk of exposure to dioxins is that background exposures are often a significant component of total exposure when based on TEQ. The average levels of background intake and associated body burdens of dioxin-like compounds in terms of TEQs in the general population (1 pg TEQ/kgBW/day and 5 ng TEQ/KgBW, respectively) are well within a factor of 10 of human-equivalent levels associated with NOELS, LOAELs, BMDs, or ED_{01} values derived from studies in laboratory animals exposed to TCDD or TCDD equivalents. Therefore, in many cases, the MOE compared to background using these endpoints is a factor of 10 or less....*

The Risk Characterization provides tabular summaries of these health endpoints that show that the MOEs for certain endpoints are even below 5. With MOEs below 10 for background exposures alone, a calculation of an MOE based on background plus incremental exposure may not be of benefit in a site-specific risk assessment. For example, if an MOE for a particular toxicological endpoint of interest is calculated to be 5 for background exposures (5/1), and it were determined that a source resulted in an incremental exposure that is 10% of background, than a resulting MOE considering background plus incremental exposure would be about 4.5 (5/1.1). While this kind information does not appear to be of benefit to decisionmakers, it may be useful to know that a particular source adds 10% more exposure than an individual would get by background exposures alone. This is identified in the third recommendation provided in the first quote above from the Risk Characterization: *"...(3) a characterization of the incremental percent increase over background of individuals or subpopulations of interest"*.

The first section below discusses the quantification of "background exposures" to dioxin-like compounds, from both a dose and body burden standpoint. The second section introduces the "increment above background", or IOB, ratio, which is a ratio that describes the percent increase over background a specific source contributes. The IOB concept is suggested as a way of evaluating non-cancer risk. The final section will discuss the traditional approach to estimating cancer risk, based on an incremental exposure and a slope factor. These approaches will be demonstrated in Chapter 5.

2.3.1. Background Exposure Doses and Body Burdens

The second volume of the Exposure Document, Volume II: Properties, Environmental Levels, and Background Exposures, describes United States background exposures to dioxin-like compounds, both from the perspective of exposure doses and body burden. Combining average adult contact rates (inhalation rate, food consumption rates, etc.) with average concentrations of these compounds in the contact media (air, food, etc.), the current adult background dose to dioxin-like compounds is quantified as 1.0 pg WHO_{98}-TEQ_{DFP}/kg-day. This Volume further provides similar background estimates for children of various ages, and these estimates are: 1-5 yrs: 3.3 pg WHO_{98}-TEQ_{DFP}/kg-day, 6-11 yrs: 1.9 pg WHO_{98}-TEQ_{DFP}/kg-day, and 12-19 yrs: 1.1 pg WHO_{98}-TEQ_{DFP}/kg-day. In addition, background exposures of infants to dioxins in breast milk is also addressed in the Volume II of the Exposure Document.

The average adult body burden of dioxin-like compounds, expressed on a lipid basis, was estimated as 25 pg WHO_{98}-TEQ_{DFP}/g (ppt). This was based on measurements of dioxins in blood of specifically selected "background" populations in six site-specific studies conducted by, or with the assistance of, the Agency for Toxic Substances and Disease Registry between 1995 and 1997, with the blood analyzed by the Centers for Disease Control (CDC, 2000). A total of 316 adults ranging in age from 20 to 70 years were measured in these studies. The individuals sampled were all U.S. residents with no known exposures to dioxin other than normal background. While the samples in this data set were not collected in a manner that can be considered statistically representative of the national population and lack wide geographic coverage, they are judged to provide the best available indication of current tissue levels in an average adult population in the United States. The Risk Characterization has estimated a national background body burden of 5 pg WHO_{98}-TEQ_{DFP}/g, on a whole weight basis.

An important issue associated with the use of this national body burden estimate is that it represents the average for the wide range of adult ages from 20 through 70. As discussed in Volume II, there is an age trend associated current body burden data - older individuals have higher body burdens. An in-depth analysis of this trend in Lorber (2002) concludes that this trend is due to two factors: 1) that exposures were higher in past, such that older individuals have been exposed to much more dioxin during their lives compared to younger individuals, and 2) that dioxins are long-lived in the human body, such that an individual's body burden will rise as they age if they receive a steady input dose during their life. Lorber (2002) concluded that higher past exposures was much more responsible for this trend than build-up over time in an individual's body. They explored this trend using simple pharmacokinetic modeling. Figure 2-1 shows one result of their analysis. These are modeled populations distributions of body burdens of dioxin and furan TEQ lipid-based concentrations (Lorber's examination didn't include dioxin-like PCBs) corresponding to the hypothetical sampling years 1965, 1985, 1995, and 2030.

There are a few important observations to make regarding the information in this figure. It shows that the average population body burdens are declining, and that by 2030, the average body burdens of WHO_{98}-TEQ_{DF} will be 9 pg/g lipid, or about 2.3 pg/g whole weight basis (assuming 25% body lipids). This trend for 2030 is essentially identical to the trend of how an individual's body burden would very slowly rise through adulthood if they are exposed to a constant dose. This result was derived by assuming that today's dose of dioxin and furan TEQs stayed constant throughout the early decades of the 21^{st} century. It also simplistically modeled dioxin TEQs as though they were a single compound with a single half-life. If one were to redo this to include dioxin-like PCBs, again modeling TEQs as though they were a single compound, it would show that the average adult body burden at the steady intake of 1.0 pg WHO_{98}-TEQ_{DFP}/kg-day would be about 13 pg WHO_{98}-TEQ_{DFP}/g-lipid, or about 3.3 pg WHO_{98}-TEQ_{DFP}/g whole weight. This figures also shows that today's background body burdens (as estimated by the population distribution for 1995) of younger individuals is lower than the population average: the population average is 28 ppt lipid while the concentrations for the under 30 age group is below 20 ppt lipid. This means that if one were to conduct an analysis of the incremental impact to specific individuals who might comprise the younger portion of an adult population, such as women of child-bearing age, it might be more appropriate to assume a lower average background body burden than the 25 pg WHO_{98}-TEQ_{DFP}/g lipid that characterizes the full range of today's population.

In site-specific assessments, the assessor has the option of using information on current national average daily intakes or body burdens as the "background" against which to compare incremental exposures. In this case, the assessor needs to make it clear that he is comparing incremental exposures and/or body burdens to national background estimates. In certain circumstances, it may be preferable to have an understanding of the "local", or "regional", background rather than the national background. A local background dose or body burden for a site-specific assessment, where a specific source of dioxin release is being evaluated, can be thought of as the overall dose or body burden that an individual potentially impacted by that source of release would experience, or would have, if the source in question were not in existence. Local background exposures for one setting may be higher than in another because, for example, one setting may have more sources of industrial dioxin release (other than the one being evaluated) within it. Another site-specific consideration would be the behaviors of exposed individuals. There may be a water body for fishing in one site, while agriculture may dominate another site. If there is reason to consider a subsistence behavior for a particular setting that could lead to elevated exposures, it may be appropriate to derive a local background exposure to dioxin based on that subsistence behavior, rather than on general behaviors.

While it may be important for risk assessors or risk managers to consider local backgrounds rather than national backgrounds, it should be emphasized that this document will not provide guidance, such as a hierarchy of recommendations, on how to assign background quantities for any quantitative evaluation of the incremental exposures using the increment above background, or IOB, approach described below. Obviously, this choice can be important. If a particular area is likely to have a higher background as compared to a national background, this would influence the numerical value of a ratio such as an IOB ratio. For example, if local background is twice as high as a national background, than an incremental exposure that is equal to 10% of national background would be equal to 5% of a local background. Similarly, if an area is thought to be have lower exposures as compared to background exposures, say half as much for example, than an incremental exposure equal to 10% of national background would be equal to 20% of a local background. Risk managers could evaluate incremental exposures differently if they are told that the incremental is 5% of background as compared to 20% of background. Perhaps the best general advice that can be offered in this procedures document is to recommend that a risk assessor supply the risk manager with this type of information: 1) the incremental exposure from a specific source, 2) how that compares to the national background exposure, and 3) information on how local exposures may relate to national exposures, if this information is available.

A local background body burden can be ascertained through monitoring. A comprehensive discussion of monitoring approaches of human matrices (blood, adipose tissue, mother's milk) is beyond the scope of this document. However, some key generalizations can be noted here that are relevant to site-specific assessments for dioxin-like compounds:

1) Whether the source is in operation or not: Some site-specific assessments are conducted to evaluate the potential impact of an industrial facility not yet operating. In that case, sampling of the representative population that could be impacted by emissions from the facility would be appropriate. If the facility has been operating, it becomes necessary to sample a population that is not impacted by the facility, but one that is comparable with regard to demographics. Dioxin body burdens are a function of many factors including age, nursing practices, dietary preferences and possibly occupational history. Ideally, the population of concern around a site should be characterized in terms of these factors. If the source is ongoing, and it becomes necessary to locate and sample a different population to characterize background, then a comparison population with similar characteristics should be chosen.

2) How to interpret differences in the study and a comparison population: Since dioxin body burdens reflect contributions from all sources, the portion due to releases from the site of concern cannot be definitively established. Sometimes measurements from a comparison population can be difficult to interpret; the better the demographic match between the study and comparison populations, the more likely it is that any differences between the groups can be attributed to the site or source of concern.

3) Body matrix to sample: As noted above, the background body burden of 25 ppt WHO_{98}-TEQ_{DFP} lipid-basis was determined from sampling of blood in background populations from several site-specific evaluations. Blood is the recommended matrix for sampling in that the entire population can be sampled in a relatively easy, non-invasive manner. In can be costly, however, and obtaining volunteers for a background blood sampling program can be an issue. Mother's milk can be considered and it does have certain advantages over blood: 1) it may be easier to obtain volunteers for a mother's milk sampling program in contrast to a blood sampling

program, 2) mother's milk has a higher lipid content (3-4 %) than blood (<1%), and therefore less milk would be required for analysis than blood, with a greater possibility of being able to quantify concentrations of the lipophilic dioxin-like compounds, and 3) useful information would be gained on potential infant impacts in addition to population exposures. However, mother's milk concentrations should be interpreted carefully, given these considerations: 1) needless to say, these programs monitor only half the population, and 2) proper interpretation of data for the female population can also be an issue. Evidence has shown that breast-feeding provides an avenue of depuration of dioxin-like compounds in the lactating female: breast milk concentrations decline while the mother is breast-feeding and female body burdens are lower for the second and subsequent children as compared to first children. As a matrix for screening studies, mother's milk can be more expedient than blood monitoring. Certainly, important implications exist when unusually high concentrations of dioxin-like compounds are found in breast milk, and general differences between populations can easily be identified in a breast milk monitoring program.

Other issues exist when deriving a background dose rather than a background body burden. A background dose estimate requires two quantities: contact rates and exposure media concentrations. Two options for contact rate assignment could be contact rates derived for a specific site (i.e., subsistence fishing consumption rates), or national average contact rates. National average contact rates were used to develop the 1 pg WHO_{98}-TEQ_{DFP}/kg-day. Four options are available for estimating exposure media concentrations:

<u>1) National average exposure media concentrations</u>: Combining site-specific contact rates with national average exposure media concentrations could provide the assessor with useful information at minimal cost, and would be quite acceptable in most cases where the assessor has no reason to believe that local concentrations are substantially different than national average concentrations. In other circumstances, it might be most appropriate to conclude that local concentrations are different than national average concentrations, necessitating a different approach for estimating concentrations.

<u>2) Measurement of Local Exposure Media Concentrations</u>: Measurement of concentrations of dioxin-like compounds in all relevant exposure media associated with a site would be the most accurate way to characterize a site-specific exposure media, but it would prove costly and, in fact, it may not be useful if the source in question has been in existence for several years. For example, a measurement of dioxins in air and soil in the vicinity of an operating incinerator source would reflect the impacts of the incinerator. Measurements in environmental/exposure media in the vicinity of an incinerator, even if it was shut down, could

still be influenced by past emissions from the incinerator. This would be the case if measuring soil around a closed incinerator. It would not be the case, however, for measuring air concentrations in a vicinity around a closed incinerator. In this case, the measured air concentrations would be appropriate reflections of background air concentrations for that site (although small contributions to that measured air concentration could come from releases of dioxins from soils; evidence suggests that these contributions would be small). The measurement of exposure media concentrations is mostly feasible (but still costly) if the assessment is prospective in nature - i.e., that it evaluates a new source not yet emitting dioxins. Another possibility is to use existing measurements or take new measurements in a nearby area which is matched as closely as possible to the study area, but doesn't have a similar dioxin source present. EPA's National Dioxin Air Monitoring Network, NDAMN, has been collecting air concentrations in background areas of the United States on a quarterly basis (4 samples/yr) since 1998 (Cleverly, et al., 2001). These concentrations could be used as background air concentrations for a site-specific assessment. However, the purpose of this network is to measure background air concentrations in settings where no apparent sources are present, such as in national parks. For this reason, NDAMN measurements might be lower than would exist in urban or suburban settings where a source of release is being evaluated with the methodologies of this document. Lorber, et al. (1998) showed how concentrations of dioxins in soil in Columbus, OH, approached a local urban background about 12 kilometers away from an incinerator. Soil or air measurements on the order of 10 kilometers or more from an air source being evaluated, but still within a very similar urban or rural setting, might be reasonable surrogates for background concentrations for specific sites.

3. Modeling of Exposure Media Concentrations: There are at least two ways in which background exposure media concentrations could be estimated with the use of models alone. One is to model the impacts from all major sources in the area being evaluated except for the source in question and then adding impacts at points of interest. This assumes that the impacts from all modeled sources are independent. The model ISCST3 used in this site-specific methodology document does, in fact, have the capability of combining inputs from multiple sources. In a complex setting, this option may be more costly and difficult than can be justified given the uncertainty in the exercise and the output. Specifically, the assessor must consider issues such as, have all sources been identified?, how accurate are source emission estimates?, and so on. Another possibility, for some time in the future, is to use results from studies now underway to develop multiple source, large-scale air dispersion/deposition models specific to dioxin. As an example, EPA is developing an application of the RELMAP model, which is the

model originally developed for acid rain assessments by EPA's Office of Air Quality and Planning Standards, and was also used to predict national fate of mercury emissions in EPA (1997b). This model takes, as input, emissions into the air from specifically defined sources in the United States, and predicts, for any location (on a 40 km grid) in the United States, deposition rates and air concentrations for modeled contaminants. Air concentrations and depositions could then serve as the input for modeling impacts to the terrestrial and aquatic environment using the steady state models discussed in this assessment. The uncertainties involved in using RELMAP and similar models to predict impacts of dioxin sources are not well quantified at the present time. EPA initiated a study in 2001 to compare modeled to measured air concentrations, and to compare RELMAP outputs to outputs generated with other similar regional models. These comparisons will help to reduce the uncertainty and to refine/calibrate these models for future possible site-specific applications involving dioxin-like compounds. Exposure media concentrations modeled by RELMAP or other aggregate source models would represent the "background" concentrations. The source in question is modeled separately and any predicted concentration would be in addition to the "background" concentration predicted by the aggregate modeling.

4. A combination of modeling and limited monitoring: This may be a reasonable way to estimate background exposure media concentrations for a specific site, if useful site-specific monitoring is available. For example, if an incinerator were no longer operating, then air concentrations measured in the vicinity of the shut down incinerator could give an estimate of the background air concentrations for that site. These air concentrations could then be routed through the terrestrial and aquatic fate models to predict soil and food concentrations for background exposure estimation. Careful monitoring of soil and air concentrations in the vicinity of the source while it is still operating is another possibility. Specifically, if several air monitors in all directions from an incinerator source were sampled on several days, during which time wind rose data were also taken, then one could probably identify air concentrations most and least likely to be impacted by the source in question by a careful examination of the wind rose data. Soil concentration data several miles away from an incinerator source, or a soil contamination source, may be an appropriate measure of dioxin impacts to soils not including the source in question. An example of careful monitoring around an incinerator emitting large amounts of dioxin allowed Lorber, et al (1998) to distinguish background air and soil concentrations from impacted air and soil. Again, these intermediate exposure media concentrations could be used with the steady-state models described in this assessment to estimate the full range of terrestrial and aquatic impacts.

A demonstration of a site-specific background scenario is presented in Chapter 5. Specifically, this scenario uses site-specific exposure factors and option 4 above to derive exposure media concentrations. Actual air and soil measurements in a background setting are used for the inhalation and soil related pathways. These measured concentrations are routed through the terrestrial and aquatic food chain models to predict concentrations in food products. Background dose estimates are calculated using these site-specific exposure factors and these hybrid exposure media concentrations. As such, the “background doses” in this example scenario in Chapter 5 can be thought of as specific to the region in which the source in question exists.

2.3.2. The Increment Over Background Concept for Non-Cancer Risk Assessment

EPA’s Office of Solid Waste (OSW) has evaluated the potential for non-cancer impacts from individual sources of dioxin release based on an “increment above background”, or IOB, approach. They have recommended that assessments conducted for hazardous waste incinerators use, on a provisional and site-specific basis, an IOB calculated as the ratio of the incremental exposure dose divided by the background exposure dose for dioxins, and then multiplying by 100%, so that the IOB is expressed in terms of a percentage. Some of the experience using this approach in OSW has been compiled and reported upon in Canter, et al. (1998). OSW has termed this ratio the margin of incremental exposure, or MOIE. That terminology and acronym will not be used here as it is similar to the MOE, or margin of exposure, which is used here and has a specific meaning in Agency risk assessing.

The other important difference is that the IOB approach developed here will be used to characterize the incremental increase to body burden and not to dose. The Risk Characterization concludes that non-cancer health effects due to dioxin exposure are best correlated to body burden and not to dose. If a dose has been occurring for a long period of time such that the body burden approaches a steady state, than of course dose and body burden are related. A percent increase in dose over background dose will be similar to a percent increase in body burden over background body burden in this circumstance. If an incremental dose has been occurring for a short amount of time, than the body burden will not rise to the level it would reach at steady state from that incremental dose. Therefore, a percent increase over background in terms of dose could be significantly higher than a percent increase over background in terms of body burden for short duration exposures. For that reason, the IOB approach developed here will be focused on body burden.

The IOB equation for body burden is given as:

$$IOB_{bb} = \frac{IBB}{BB_{bk}} * 100\% \qquad (2\text{-}2)$$

where:

IOB_{bb}	=	increment over background ratios for body burden (bb), %
IBB	=	increment of body burden increase due to the incremental exposure, pg/g whole weight
BB_{bk}	=	background body burden, pg/g whole weight basis

To use this equation, a background body burden needs to be assigned, and an approach needs to be developed to estimate the increment of body burden that is due to the source being evaluated. Discussions in the previous section address the assignment of the background body burden. As discussed above, issues to consider include: whether to use a national or a local background body burden, whether to consider the background body burden for younger adults rather than the full range of adult ages (younger adults would have a lower background body burden), whether to consider specific populations such as women of child-bearing age (which again might imply a lower concentration as compared to a full population average), and so on.

The focus on the procedures in this volume are on predicting exposure media concentrations and estimating site-specific intake doses. A simple procedure is recommended here to estimate body burdens given intake doses to dioxin-like compounds. Specifically, the simple one-compartment, first-order pharmacokinetic model is recommended. The non steady-state form of this model to predict body burden from a constant intake dose is given by:

$$L \frac{dC_L}{dt} = D - kLC_L \qquad (2\text{-}3)$$

where:

C_L	=	concentration in lipid, pg/g;
L	=	lipid mass, g
	=	BW * F_{lipid} (= body weight * fraction lipid)
D	=	steady-state absorbed dose, pg/day (* 365 d/yr = pg/yr)
k	=	first-order dissipation rate constant, 1/day (or 1/yr, if D is in 1/yr units)

= $0.693/t_{1/2}$

$t_{1/2}$ = half-life, days (or years)

t = time period of interest, most often the full duration of exposure

The closed form solution for Equation (2-4) is given as:

$$C_L(t) = C_L(0)\ e^{-kt} + \frac{D}{kL}\ (1 - e^{-kt}) \qquad (2\text{-}4)$$

The first term on the right hand side of Equation (2-4) describes the decline in an initial body burden. If using Equation (2-4) to solve for the full body burden after a period of exposure denoted by "t", than one has to also assign a value of "D" equal to the incremental dose plus the ongoing background dose times an absorption fraction. However, if using this solution to estimate the incremental body burden due to the incremental dose only, than the first term drops out and the equation for solving IBB is:

$$IBB = \frac{ADD\ AF}{kL}\ (1 - e^{-kt}) \qquad (2\text{-}5)$$

where the term "D" has been replaced by ADD * AF, where ADD is the average daily incremental dose, and AF is the absorption fraction. The Risk Characterization has assumed a value of 0.8 for the absorption fraction, 70 kg for the body weight (BW) and 7.1 years for the half-life ($t_{1/2}$), when using this model for WHO_{98}-TEQ_{DFP} in a backwards mode to estimate a steady-state dose that is associated with a body burden. For site-specific assessments, the assessor can assign values to these parameters based on whether they intend to model individual dioxin-like compounds (which could influence the assignment of $t_{1/2}$ or A) and/or whether they intend to consider different sexes and/or stages of life (which could influence the assignment of BW).

2.3.3. Traditional Agency Cancer Risk Assessment Procedures

The usual procedure used to calculate an upper-limit incremental cancer risk is based on an assessment of lifetime average daily dose, LADD, and a slope factor, as follows:

$$R \quad = \quad 1 - e^{SF*LADD} \;\approx\; SF * LADD \qquad (2\text{-}6)$$

where SF is the slope factor, or more precisely, the 95% upper confidence limit of the linearized cancer slope factor of the dose-response function (expressed in units of the probability divided by dose, or probability/[mg/kg-day], which is most often simply shortened to $[\text{mg/kg-day}]^{-1}$) and LADD is the dose (which needs to be in units appropriate to cancel those of SF, mg/kg-day). The estimated R in Equation (2-6) can be understood as the 95% upper confidence probability of incurring cancer during a lifetime as a result of the exposure defined by LADD; the true probability may be less than the quantity R, and may even be zero. The simplified form of the risk equation shown above is reasonably accurate for risks less than 10^{-2}. This assessment uses the simplified SF * LADD form of this equation since the exposures and risks demonstrated are generally less than 10^{-3}. The slope factor, SF, for 2,3,7,8-TCDD has been previously estimated by EPA as $1.56*10^5$ $[\text{mg/kg-day}]^{-1}$ (EPA, 1984; 1981), but has been reevaluated as $1.0*10^6$ $[\text{mg/kg-day}]^{-1}$ in this Reassessment. Also, it has been recommended in the Risk Characterization that it be applied to a TEQ dose, in addition to a 2,3,7,8-TCDD dose. As detailed in the Risk Characterization, a current estimate of lifetime cancer risk from background exposures to dioxin-like compounds is about 10^{-3}. This is calculated simply as the background exposure dose of 1 pg WHO_{98}- TEQ_{DFP}/kg-day times the slope factor of $1*10^{-3}$ (converted to [pg WHO_{98}-TEQ_{DFP}/kg-day$]^{-1}$ to be consistent with the dose units).

Similar to the estimation of lifetime cancer risk demonstrated above showing a risk of 10^{-3} due to background exposure to dioxin-like compounds, assessors can also estimate the incremental cancer risk in these probability terms. The LADD of Equation (2-6) would simply be $LADD_{ss}$. These LADDs can be for individual exposure pathways assessed, or all exposure pathways combined.

When using Equation (2-6) for estimating incremental cancer risk, the assessor needs to be aware that adjustments may be required for particular pathways. Adjustments are necessary for the soil-related pathways, soil ingestion and soil dermal contact. The selected cancer slope factor was based primarily on the analysis of the human epidemiology studies where exposure was estimated from dioxin concentrations in blood in occupationally exposed cohorts. The dose estimates used to derive the slope factor were obtained by using a pharmacokinetic model to convert the blood concentrations to an administered, or potential, dose. An administered dose is defined as the dose which contacts the body boundary surfaces, such as the skin as in dermal exposure or the dose ingested prior to absorption. This administered dose was derived by first calculating an absorbed dose and then dividing by 0.8 - i.e., an absorbed dose was assumed to be 80% of an administered dose. Because the slope factor was derived based on an administered dose, the new slope factor can be applied to an administered dose without any adjustment for absorption as long as the absorption is approximately 80%. Although the data are limited, this is probably a reasonable assumption for most types of food ingestion and inhalation.

The absorption from ingested soil or dermal exposure from soil, however, is likely to be less than 80%. Studies have shown that the bioavailability of dioxin from ingested soil is variable depending on properties such as organic carbon content and is best determined on a site specific basis. A full discussion on absorption of administered dioxin through the various pathways can be found in *Chapter 1. Disposition and Pharmacokinetics*, of the Health Document (Part II of these Dioxin Reassessment Documents). Assuming that 30% of dioxin in ingested soil is absorbed, then the slope factor should be multiplied by 30/80 or 0.375 before combining it with the ingested dose to compute risk. For the soil dermal pathway, the absorption of dioxin through the skin has been estimated to range from 0.5 to 3.0% (EPA, 1992a), with assessments typically (conservatively) assuming 3.0%. This assessment adopts the 3% value to calculate the dose of dioxins absorbed through soil dermal contact. As will be described below, this absorption fraction is already considered in the calculation of dioxin dose through soil dermal contact, and the calculated dose is already an absorbed dose. As such, the correction factor is a little different for soil dermal contact - its purpose is to convert a 100% absorbed dose into a dose comparable to other administered doses to which the SF is applied. Specifically, it needs to be adjusted downward to be equivalent to, for example, an inhaled administered dose which is 100% as calculated by the procedures here, but it only 80% (or thereabouts) when absorbed. Therefore, the dermal dose, needs to be adjusted upward by a factor of 1.00/0.8, or 1.25, to be used with the SF. The adjustments for the soil pathways to estimate cancer risk are given as:

$$R_s = SF\ LADD_s\ AF_s \tag{2-7}$$

where:

where:	R_s	=	lifetime excess cancer risk from soil pathways, ingestion and dermal contact
	SF	=	cancer slope factor, $(mg/kg\text{-}day)^{-1}$
	$LADD_s$	=	administered dose from soil ingestion and soil dermal contact, mg/kg-day
	AF_s	=	absorption correction factor for the soil pathways, 0.375 for soil ingestion and 1.25 for soil dermal contact

An assessor can easily apply the IOB concept for cancer risk: simply divide the incremental cancer risk by an appropriate background cancer risk, and then multiply by 100% As noted above and discussed in the Risk Characterization, the current average background cancer risk is 10^{-3}. One can use this national average cancer risk estimate or derive a site-specific background cancer risk by determining a site-specific LADD and multiplying it by the slope factor. For example, if the incremental cancer risk is 10^{-5}, and the national background cancer risk of 10^{-3} is used, then the IOB for cancer risk is estimated as 1%.

2.3.4. Interpretation of Cancer and Non-Cancer Risk Assessment Results for Dioxins

Chapter 5 will demonstrate the procedures for estimating incremental cancer risk and for characterizing non-cancer risk for dioxin-like compounds using the IOB approach. This demonstration will include generation of site-specific background estimates of dose and body burden that are distinct from the national averages above, and the generation of the IOB and incremental cancer risk estimates. However, no interpretations for these results will be provided. Interpretations of risk assessment results is where risk management takes over, and it is beyond the scope of this document to provide risk management guidance for assessing incremental impacts of the dioxin-like compounds from specific sources of release.

Still, some general comments can be provided here as background. For cancer risk for compounds other than the dioxin-like compounds, EPA has based regulatory actions on a wide spectrum of levels, generally in the range of 10^{-6} to 10^{-4} lifetime cancer risk. Estimated lifetime individual risks below 10^{-6} have rarely been found to be sufficient basis for action, while in most cases levels above 10^{-4} result in some form of action, although not necessarily regulation. As described above, the current background cancer risk from exposure to dioxin-like compounds is at 10^{-3}. In performing a site-specific assessment for a specific source of dioxin release, an assessor should assume that an individual’s exposure and resulting lifetime cancer risk to dioxin-like compounds are already at 10^{-3} (or a different site-specific lifetime cancer risk) and that the source adds to this impact. For example, if assessing impacts to farmers who live near an incinerator and consume a portion of their agricultural produce, it must be assumed that their produce has dioxin concentrations already at background levels and that the incinerator emissions add to this concentration. The challenge for risk managers in such a circumstance is to determine what level of incremental lifetime cancer risk posed by the specific source warrants concern, when the background lifetime cancer risk is already at a level near where, for other contaminants and other circumstances, EPA has historically judged that some form of action may be warranted.

Similar issues arise when trying to put the site-specific IOB in perspective. As discussed above, the MOE for background exposures for non-cancer effects is already in a range (<10) that is of concern. An incremental exposure will decrease this margin.

In both cancer and non-cancer risk assessment, therefore, traditional rules-of-thumb may not be of immediate use to the risk assessor, because background levels translate to concern as defined by traditional Agency methods. The Risk Characterization recognizes the difficulty posed by this circumstance, and suggests that the Agency take a broad, long-term view of dioxin risk management:

> *In this case, a strategy might be to bring average "background" exposures down and to also focus on larger incremental exposures or highly susceptible populations. This would be a strategy that would parallel the Agency's approach to control lead exposures. Other parallel science and management issues between dioxin-like compounds and lead are under discussion within the Agency. Providing guidance on the how to judge the significance of incremental increases to background using the MOE approach is beyond the science scope of the reassessment and will have to be addressed elsewhere by EPA.*

2.4. THE TOXIC EQUIVALENCY PROCEDURE

Assessments very rarely focus on 2,3,7,8-TCDD alone, but rather on the suite of 17 dioxin and furan dioxin-like congeners, and also the 12 dioxin-like coplanar PCBs. Chapter 1 describes the "toxicity equivalency factor", or TEF, approach to handling mixtures of dioxin-like compounds. The TEF for a congener of interest is a measure of the potency of that congener divided by the potency of 2,3,7,8-TCDD. As shown in Table 1-1 in Chapter 1, the TEFs for 2,3,7,8-TCDD and 1,2,3,7,8-PCDD are 1 and all other dioxin-like compounds have TEFs less than 1. The combined risk resulting from exposure to a mixture of dioxin-like compounds can be computed using the TEFs and assuming that the risks are additive. This assessment recommends that assessors model the fate of all the congeners individually until the estimate of the exposure media concentration is made. At that point, the Toxic Equivalent exposure media concentration, C_{TEQ}, can be calculated as:

$$C_{TEQ} = \Sigma \, TEF_i \, C_i \qquad (2\text{-}8)$$

where C_i is the concentration of the individual congener. LADDs and ADDs can then be estimated for a TEQ concentration. Cancer risk on a TEQ basis can be assessed using the q_1^* for 2,3,7,8-TCDD in combination with the TEQ-based LADD. Non-cancer risk procedures are similarly driven by TEQ body burdens or increments above background.

2.5. PROCEDURE FOR ESTIMATING EXPOSURE

Section 2.2 described the exposure equation as it applies to dioxin and dioxin-like compounds. Before making exposure estimates, the assessor needs to gain a more complete understanding of the exposure setting and be prepared to estimate exposure media concentrations. The purpose of this section is to provide guidance for the procedures followed in this assessment to define such settings and estimate exposure media concentrations. The approach used here is termed the exposure scenario approach. Brief descriptions of the steps and associated document chapters are presented below.

Step 1. Identify Source

Three principal sources are addressed in this document. The first, identified as "soil contamination", is called a source in that the starting point of the assessment is a bounded area of soil contamination. Of course, the ultimate source for soil contamination is some unidentified cause for the soil to become contaminated. For exposure and risk assessment purposes, the cause for contamination is not relevant except to assume that the cause is not ongoing and that the impact of the "initial" levels is what is being evaluated. For contaminated soils, exposures could occur on the site of contamination or distant from the site of contamination. Examples of on-site exposures include exposures to workers on Superfund or similar sites, or special circumstances such as Times Beach where residential properties become contaminated. A common example of an off-site impact would be impacts to residents who live near a Superfund (or similar) site whose property becomes contaminated due to erosion and whose air contains elevated levels of the contaminant due to dust erosion or volatilization followed by atmospheric transport. The second principal source is called "stack emissions." Unlike the soil source, the contamination is assumed to be on-going. Stack emissions in particulate form are assumed to deposit onto the soil and vegetation at the site of exposure, and emissions in vapor form result in air-borne concentrations which transfer into vegetation at sites of exposure. It is noted that individuals working at the site where stack emissions occur are also exposed. The procedures in this document only apply to residents who are not associated with the site where stack emissions occur. The third principal source is called "effluent discharges". Such discharges represent point source inputs to surface water bodies. Like the stack emission source, impacts to surface water bodies are assumed to be ongoing during the period of exposure. Unlike either of the above two sources, only the impacts to water and fish are considered for this source category.

Step 2. Estimate Release Rates

Estimating the release of contaminants from the initial source is the first step towards estimating the concentration in the exposure media. Releases from soil contamination include volatilization, and wind and soil erosion. Chapter 4 on estimating exposure media concentrations describes fate and transport modeling procedures for estimating soil releases. Stack emissions and effluent discharges are point source releases into the environment. Background on stack emissions including details on modeling from the stack to a site of exposure are provided in Chapter 3.

Step 3. Estimate Exposure Point Concentrations

Contaminants released from soils, emitted from stacks, or discharged into surface waters move through the environment to points where human exposure may occur. Contaminated soil that is near but not at the site of exposure is assumed to slowly erode and contaminate the exposure site soil, but to a level lower than the level at the contaminated site. The only time when the source concentrations equal the exposure concentrations is for the soil pathways, soil ingestion and dermal contact, when the soil contamination is at the site of exposure. Chapter 3 describes the use of the ISCST3 Model to estimate dispersion of stack plumes to predict air-borne concentrations at the site of exposure as well as deposition rates of dioxins sorbed to stack emitted particulates. Chapter 4 describes how soil and vegetation concentrations are estimated given contaminant concentrations and deposition rates, and also how release rates from soil initially contaminated translate to exposure point concentrations. Chapter 4 also describes a simple dilution model which translates effluent discharges into surface water and fish tissue concentrations.

Step 4. Characterize Exposed Individuals and Exposure Patterns

The patterns of exposure are described in Sections 2.6 and 2.7 of this Chapter. Exposed individuals in the scenarios of this assessment are individuals who are exposed in their home environments. They are adult residents who also recreationally fish, have a home garden, farm, and are children ages 2-6 for the soil ingestion pathway. Each of these pathways is evaluated separately. Although it is unlikely that individuals would experience all of these pathways simultaneously, quite often exposure assessments do add exposures across pathways. In this document, the doses across pathways are added. Exposure pathways evaluated, which have generally been alluded to in discussions above, include inhalation, ingestion, and soil dermal contact. Each pathway has the set of parameters including contact rates, contact fractions, body weights, and lifetime. These parameters were defined earlier in Section 2.2.

Step 5. Put It Together in Terms of Exposure Scenarios

A common framework for assessing exposure is with the use of "settings" and "scenarios." Settings are the physical aspects of an exposure area and the scenario characterizes the behavior of the population in the setting and determines the severity of the exposure. A wide range of exposures are possible depending on behavior pattern assumptions. An exposure scenario framework offers the opportunity to vary any number of assumptions and parameters to demonstrate the impact of changes to exposure and risk estimates. Exposure estimates for six example scenarios are demonstrated in Chapter 5.

Step 6. Estimate Exposure and Risk

Section 2.2 described the basic equation that estimates exposure for every assumed pathway in an exposure scenario. Chapter 5 demonstrates the methodology on six example scenarios, which includes the generation of exposure estimates for ten different exposure pathways and the suite of 17 dioxins and furans, and one dioxin-like PCB.

Step 7. Assess Uncertainty

Chapter 7 provides a discussion on model validation and provides several exercises where the models of this assessment were validated with real world data. Chapter 8 addresses the issue of uncertainty more generally, identifying possible sources of uncertainty associated with this methodology. These uncertainties should be considered when applying this procedures to a particular site. Chapter 6 on User Considerations includes discussions on other pertinent topics such as sensitivity of model results to parameter selection, and judgements on use of the parameters selected for the demonstration scenarios for other applications.

2.6. STRATEGY FOR DEVISING EXPOSURE SCENARIOS

EPA (1992b) states, "In exposure scenario evaluation, the assessor attempts to determine the concentrations of chemicals in a medium or location and link this information with the time that individuals or populations contact the chemical. The set of assumptions about how this contact takes place is an exposure scenario." These assumptions can be made many different ways producing a wide variety of scenarios and associated exposure levels. The number of people exposed at different levels form a distribution of exposures. Ideally, assessors would develop this entire distribution to fully describe the exposed population. Such distributions could be defined using Monte Carlo techniques if sufficient input data are available. However, as discussed in Section 2.1 above, generic issues surrounding use of Monte Carlo are not evaluated here. Discussions of how other assessors have applied Monte Carlo to problems involving dioxin-like compounds are presented in Chapter 8. Since the necessary information for developing a population distribution is rarely available, EPA (1992b) recommends developing a central and high end scenario to provide some idea of the possible range of exposure levels. Since that set of guidelines, an additional set of guidelines had been developed (Browner, 1995) which reaffirms this recommendation for central and high end risk descriptors, and adds other recommendation to identify “highly susceptible” or “highly exposed” subpopulations. There have also been instances where an EPA program office has provided guidelines which specify, almost in cookbook fashion, the make-up of exposure scenarios for evaluating a source. EPA’s Office of Solid Waste and Emergency Response provided such guidance for evaluation of hazardous waste incinerators (EPA, 1994b). US EPA’s Region 6 has more recently published similar guidance for hazardous waste incinerators (EPA, 1998).

This section will illustrate the concept of central and high end scenario development as it could be applied to specific sources of release of the dioxin-like compounds. In addition, this section identifies the exposure pathways which are relevant to these compounds, and provides background and justification for the exposure parameters which were selected for the demonstrations in Chapter 5.

For any physical setting, a wide variety of exposure scenarios are possible. The range of exposure levels results from a number of different factors including individual behavior patterns, proximity of individuals to the source of contamination, the fate characteristics of the contaminant, and others. In order to illustrate the possible range, the assessor should try to characterize a central and high end scenario. The general strategy recommended here for defining these scenarios is to first identify and quantify the source of contamination. Next, the assessor should determine the geographic area that is impacted by this source. The contaminant levels are likely to vary widely over this area. Select locations of interest within this area such as the location of the nearest exposed individual or most heavily populated area. For each of these locations, identify behavior patterns which characterize central and high end exposure patterns. Central scenarios correspond to average or median levels and high end scenarios are defined as levels above the 90th percentile but within the actual range of exposure levels (EPA, 1992b; Browner, 1995).

Statistical data are rarely available to precisely define such scenarios. Instead, judgement is usually required to identify behavior patterns meeting these criteria. For example, most rural areas probably include both farming and nonfarming residents. Farmers who grow or raise a portion of their own food could be selected to represent the high end scenario and those living in typical residential areas could represent the central scenario. Alternatively, if more detail is desired, central and high end scenarios could be defined for both segments of the population, i.e., farmers and residents. For each scenario, determine relevant exposure pathways and assign values for exposure parameters such as contact rate, exposure duration, and so on, which represent a central and/or high end pattern for the type of receptor. Finally, compute the associated exposure level. The resulting range of exposure levels for each location can be used to illustrate the possible range of exposures.

Reference has been made in this chapter to the example scenarios found in Chapter 5, Demonstration of Methodology. Three "source categories", categories of contamination sources described in Chapter 4, are demonstrated in Chapter 5. The stack emission source is assumed to expose a relatively large population in a rural area containing residences and farms. For this source, both central and high end scenarios are defined in the manner outlined above. Specifically, a central scenario is based on typical behavior at a residence and the high end is based on a farm family that raises a portion of its own food. For the soil contamination and effluent discharge sources, only one scenario each will be defined and demonstrated. The soil contamination category will be demonstrated with a high end scenario - a farm is located near the site of contamination. Soil on the farm becomes impacted through the process of soil erosion. Other individuals within a community can also be impacted by a site of high soil contamination. Such individuals would include those visiting or trespassing on the site, volatilized residues can reach their residences, they may obtain water and fish from a nearby impacted water body, and so on. As such, alternate scenarios demonstrating the impact of a site of soil contamination could be developed. For the sake of brevity, and also considering that those residing nearest the contaminated are most impacted, only a high end scenario is developed for the soil contamination source category. The effluent discharge source category is unique in that only the pathways of water ingestion and fish ingestion are considered. For this category, fish and water ingestion patterns will be those adopted for the central scenarios. Again, other patterns of fish and water ingestion could be evaluated for this source category. As a matter of brevity again, only central patterns of behavior with regard to fish and water ingestion are demonstrated.

Two other scenarios, a central and a high end scenario, will be developed for "background" conditions. In this special circumstance demonstrated in Chapter 5, a unique point source such as a tall stack or an effluent pipe, or diffuse source in the case of a large area of soil contamination, is not considered. Rather, all the soil in a hypothetical setting contains dioxins at background levels. Similarly, the air concentration in the hypothetical setting will be initialized to background levels of dioxins. This demonstration will use fate and transport algorithms that have been developed for both the soil contamination source category as well as the stack emission source category. Further details of this structure are described in Chapter 5.

Finally, Chapter 5 will demonstrate some of the pathways outside the scenario structure. These include the chicken and the egg ingestion pathways. These were not included in the central or high scenario because it seems somewhat unlikely to assume that individuals living on farms in rural settings would generate quantities of several food items simultaneously on the farm or homestead. In a real setting, it may be plausible that there are farmers who raise cattle and use a portion of their stock to supply the family with beef and/or milk, farms or residences where chickens are raised that provide the family with eggs and/or chickens, and so on, but it is unlikely that a single farm would raise two or more distinct food animals. Also, if a farm is producing foods that are consumed locally, than a high end scenario could be comprised of individuals who don't live on farms but who do consume local foods. In this document, the high end scenario is defined as a farm raising only one type of terrestrial animal which is used to supply the family with terrestrial animal food products; specifically, the farm family raises cattle and consumes beef and milk from their own stock.

The methodologies used to estimate exposure media concentrations are described in Chapter 4 as screening level in their technical sophistication, but site specific in their application. Defining populations that are typical of central and/or high end exposures is clearly a site specific exercise. Assessors need to make the kinds of assumptions discussed here for their own source and populations of concern. Many acceptable ways could be used to define central and high end scenarios. The approach used here was done for demonstration purposes only. On the other hand, the example scenarios in Chapter 5 were carefully crafted to be plausible and meaningful, considering key factors such as source strength, fate and transport parameterization, exposure parameters, and selection of exposure pathways.

Key source strength terms were carefully developed and defined. These include soil concentrations, effluent discharge rates, and stack emission rates. For the demonstration of the soil contamination category, for example, the concentration of 2,3,7,8-TCDD and two other example compounds were set at 1 ppb, which was a typical concentration of 2,3,7,8-TCDD found in Superfund-like sites studied in the National Dioxin Study (EPA, 1987). Concentrations in soil in the demonstration of background conditions were characterized as typical of background levels and were based on concentrations found in rural settings. Researchers investigating concentrations of 2,3,7,8-TCDD in "background" or "rural" settings have typically found it in the ppt range or not detected it (with a detection limit generally less than 1 ppt), which contrasts the 1 ppb assumed for 2,3,7,8-TCDD in the demonstration of the soil contamination source category. Introductory sections of Chapter 5 provide a more complete description of the example scenarios.

2.7. EXPOSURE PATHWAYS AND PARAMETERS

The dioxin-like compounds have been found primarily in air, soil, sediment and biota and to a lesser extent in water. Thus, the most likely exposure pathways are:

- Ingestion of soil, water, terrestrial animal food products (beef, pork, chicken, eggs, dairy products), fish, fruit, and vegetables
- Dermal contact with soil
- Inhalation of particulates and vapors.

The following sections describe the selection of central and high end exposure parameters for these pathways. Table 2-1 summarizes all the exposure parameters selected to represent the central and high end demonstration scenarios of Chapter 5.

2.7.1. Soil Related Exposures

The two soil related exposures which will be demonstrated in this assessment include a childhood pattern of soil ingestion and an adult pattern of soil dermal contact. The soil ingestion pathway will involve the assignment of central and high ingestion quantities in units of mg/day and it will assume a child body weight of 17 kg. This contrasts the food pathways described below in Section 2.7.4, where the contact rate is defined in units of g/kg/day. Parameters for the soil dermal contact pathway were developed using the Exposure Factors Handbook (EPA, 1997a). Further details on this pathway can be found in EPA’s Dermal Exposure Assessment: Principals and Applications (EPA, 1992a).

2.7.1.1. *Soil Ingestion*

Soil ingestion occurs commonly among children during activities such as mouthing of toys and other objects, nonsanitary eating habits, and inadvertent hand-to-mouth transfers. In addition to normal soil ingestion activities, some individuals exhibit behavior known as pica which involves intentional soil ingestion. Soil ingestion rates associated with pica are probably much higher. Very limited values for pica patterns have been reported in the literature. Based on some limited data, EPA (1997a) reports that a 5 to 10 g/day for deliberate soil ingestion rates for children may not be unreasonable. This dioxin assessment considers only normal soil ingestion among children.

To a lesser extent, soil ingestion also occurs among adults from activities such as hand-to-mouth transfer when eating sandwiches or smoking. However, the data to estimate the adult rate of soil ingestion is scarce. EPA (1997a) notes that the data available on adult soil ingestion is consistent with a 50 mg/day assumption often used by EPA program offices to model this pathway. Adult soil ingestion is not demonstrated in this assessment. Paustenbach (1987) and Sheenan et al. (1991) have suggested calculating exposures for this pathway (as well as dermal contact and inhalation) separately over three to four age periods to reflect major changes in body weight, surface area and inhalation rates. In general, exposure assessments can be refined by estimating exposures separately over each year of age that is of interest and summing to get the total. Age specific data for body weight, surface area and inhalation rate are presented in EPA (1989, 1992b, and 1997a). These procedures are not presented here, but readers interested in refining exposure estimates are encouraged to check the above references for further guidance.

Based on the review of literature, EPA (1997a) suggests that a child soil ingestion rate of 100 mg/day appears to represent a central estimate of the mean for children under 6 years old. This value will be adopted for the central scenarios. Of the studies which were considered appropriate in EPA (1997a), upper percentile values ranged from 106 mg/day to 1,432 mg/day with an average of 383 mg/day for soil ingestion and 587 mg/day for soil and dust ingestion. On this basis, a value of 600 mg/day will be used for the high end exposure.

In cooler climates where the children may have little exposure to outdoor soils for a significant portion of time, it may be appropriate to develop a time-weighted average daily soil ingestion rate based on indoor and outdoor behaviors. Hawley (1985), for example, assumed that young children ingest 100 mg of housedust per day while spending all their time indoors during the winter months, that they ingest 250 mg/day while playing outdoors during the summer months, and that they ingest 50 mg/day while playing indoors during the summer. His time-weighted annual average, considering this different summer and winter patterns, was calculated at 150 mg/day.

For the soil ingestion pathway, contact fraction refers to the portion of ingestion soil which is contaminated. For the residential setting, the assumption is made here that all soil ingestion by children occurs in and around the home, and that all the soil at the home is contaminated. Thus, a value of 1 has been adopted in the example scenarios presented in Chapter 5. In situations where the contaminated area is located remote from where children live, and children have some access to these areas (if the areas are parks or playgrounds, e.g.), lower fractions would be appropriate.

Another issue for the soil ingestion, and the soil dermal contact pathway discussed below, is the concentration of dioxin-like compounds to which individuals are exposed. As described later in Chapter 4, two “source categories” discussed in this document include stack emission sources and off-site soil contamination (i.e., a site of soil contamination distant from the site of exposure). Dioxins arrive at the site of exposure either from the air, as in the stack emission source, or via overland erosion, as in the off-site soil contamination scenario. Residues of dioxin mix into either a shallow (2 cm) depth of soil which is “untilled”, or a 20-cm depth which is “tilled” (by gardening or farming). Obviously, tilled concentrations are lower than untilled concentrations. Given that ingestion is only modeled for children who are likely not too heavily involved in gardening or farming, it is assumed that their contact is with untilled soils, and the higher concentration associated with these soils is used.

2.7.1.2. *Soil Dermal Contact*

The total annual dermal contact to soil alone, expressed in mg/yr, is the product of three terms: the contact rate per soil contact event, the surface area of contact, and the number of dermal contact events per year. The soil contact rate is also known as the soil adherence rate to reflect that it is not only the amount of soil contacted, but the amount of contact that adheres. Current guidance in the Exposure Factors Handbook (EPA, 1997a) suggest that soil dermal exposure can be divided into components for indoor and outdoor exposures; for indoor exposures, the medium might be better described as “indoor dust”, and for outdoor exposures, the medium would be soil. The adherence rate is also a function of the body part - with hands usually having the highest adherence, with other exposed parts such as arms and legs usually having lower adherences. The Exposure Factors Handbook provides details on these factors. A summary pertinent to the applications demonstrated here is:

- Contact rate: <0.002 to >20 mg/cm^2-event. The very high adherence rates were found for the scenario described as, “kids-in-mud”, and was from data on children playing by a lakeshore. The lower range was found for an indoor Tae Kwon Do setting. Adherences for a day-care setting ranged from 0.03 for arms and legs to

0.1 for hands. Outdoor adherences for gardeners ranged from 0.005 for legs to 0.02 for arms to 0.2 for hands.

- Body surface area: Average adult and child body surface areas are in the neighborhood of 20,000 and 6500 cm^2 (for a child ages 2-5). The selection of the surface area considered for a dermal contact event depends on the nature of the event and the assumptions about which part(s) of the body are involved in that event. For a child ages 2-5, hands comprise about 5.5% of total body surface area, arms about 13%, and legs about 25%. For adults, hands are similarly about 5%, arms are about 13%, and legs about 32%.
- Event frequency: This is a factor more based on exposure assessment judgement, rather than data, as in the above two factors. Obviously, climate, activity, age, and similar factors play into assignment of this parameter. This factor can be expressed in terms of events per time period, usually events/yr. For consistency in use in the exposure equation, it is usually transformed to an event/day basis.

All other pathways assessed here estimate an “administered” or “potential” dose, which is defined as the dose which comes in contact with the body. For this pathway, however, an “absorbed” dose will be estimated. This is because for all other pathways, a significant amount of the dose that comes in contact with the body is absorbed - about 80% for the inhalation and ingestion pathways (except for soil ingestion, when the fraction absorbed is more like 30%). An absorption fraction, or AF, is added in the calculation of a LADD for the dermal contact pathway. EPA (1992a) reviews the data to conclude that the absorption of dioxin through the skin has been estimated to range from 0.5 to 3.0%. This document will adopt the conservative estimate of 3.0%, or an AF of 0.03, to give the following for LADD for the soil dermal contact pathway:

$$LADD_{dc} = \frac{C_s\ CR\ SA\ EF\ AF\ ED\ 10^{-6}}{AT\ BW} \qquad (2\text{-}9)$$

where:

$LADD_{dc}$	=	lifetime average daily dose due to soil dermal contact, mg/kg-day
C_s	=	concentration in soil, mg/kg
CR	=	contact, or adherence, rate, mg/cm^2-event
SA	=	surface area of contact, cm^2

EF	=	event frequency, events/day
AF	=	absorption fraction, 0.03
ED	=	exposure duration, yr
AT	=	averaging time, 70 yr for LADD
BW	=	body weight, kg
10^{-6}	=	units conversion factor, kg/mg

In this document, soil dermal contact exposures are demonstrated only for an adult for a "gardening" central tendency pathway and a "farming" high end pathway. Indoor activities for both the central and high end scenarios will assume Tae Kwon do-like activities which translate to a contact rate of 0.005 mg/cm^2-event, with dermal contact only with the hands which translates to 1,000 cm^2 (20,000 cm^2 total surface area * 5% surface area for hands) and 1 event per day (or 365 times per year). Outdoor dermal contact will be modeled on a gardening scenario for the central scenarios and a farming scenario for the high end pathways. The gardening scenarios assume 0.03 mg/cm^2 for contact rate, 10,000 cm^2 surface area contact which assumes hands, arms, and legs, and 0.27 events/day (or 100 events/yr). In comparison to outdoor gardening, the farming scenario assumes a greater adherence at 0.1 mg/cm^2, a smaller surface area of 3600 cm^2 which assumes hands and arms only, more frequent events at 0.96 events/day (or 350 events per year).

Another difference between indoor and outdoor activities in this assessment is the concentration to which the individuals are exposed. As described in the previous section on soil ingestion, tilled (lower in concentration) and untilled (higher) soil concentrations are derived for the stack emission and off-site soil contamination sources. In this assessment, outdoor dermal contact events are assumed to occur in association with tilled soils (gardening or farming), while indoor contact events are assumed to occur in association with untilled soils.

2.7.2. Vapor and Dust Inhalation

EPA (1997a) describes the derivation of ventilation rates, which include assumptions regarding number of hours in sleep, hours inactive, and hours in various levels of activity. Several inhalation studies are reviewed. The final recommendation for continuous exposure assessments in which specific activity patterns are not known is 13.3 m^3/day based on Layton (1993). A rate of 13.0 m^3/day (rounded for simplicity) will be adopted in this assessment. EPA (1997a) suggests that a value of 20 m^3/day represents an upper percentile estimate among adults, and this will be adopted in this assessment as a high end.

The contact fraction for this pathway is equal to the fraction of total inhaled air which is contaminated. Thus it relates largely to percent of time spent in the contaminated area. For the demonstration scenarios in Chapter 5, the contaminated area is the home environment. Therefore, information on the time spent at home versus away from home is pertinent. In EPA (1997a), several activity pattern studies are reviewed. Two of the studies reviewed contained information on time spent at home and away from home, and both studies had very similar results for time spent in the home environment. Robinson and Thomas (1991) reviewed and compared data from the 1987-88 California Air Resources Board (CARB) time activity study with a similar 1985 national study titled, "American's Use of Time." In an average day comprising 1440 minutes, Robinson and Thomas (1991) found an average of 954 minutes at home from the national study, or 66% of the time, compared to 892 minutes (62%) for Californians. Sexton and Ryan (1987) reviewed the procedures for assessing inhalation exposures, and in so doing, reviewed two previous studies on time use including information on time at home and away from home. One study showed 69% of the time at home and the second study showed 71%. Based on these, a central estimate for the fraction of time spent at home will be 70%.

EPA (1997a) did not make specific recommendations for a high end contact fraction. Such a fraction should be relevant to the population defined as high end, which in this assessment is a subsistence farm. It seems reasonable to assume that a rural farming family may have more time at home as compared to the general population. Without rigorous justification, a high end contact fraction will be assumed to be 90%.

The two key parameters discussed above, contact rate and contact fraction, when multiplied together, will yield a contact rate for contact with the contaminated media. For the central scenario, the two key quantities are 13.0 m^3/day and 0.70, which yield a contact rate with impacted air of 9.1. For the high end scenario, this calculation is 20.0 m^3/day times 0.90, which is 18 m^3/day. Therefore, the difference between central and high end from behavior assumptions alone is about a factor of two.

An additional assumption needs to be made for the vapor and dust inhalation pathways. This pertains to an assumption concerning the differences in air quality between indoor and outdoor conditions. Algorithms for both particulate and vapor-phase air-borne concentrations of contaminants are specific to outdoor air. Hawley (1985) assumed, based on several other studies in which measurements were made, that the concentration of suspended particulate matter in indoor air is equal to 75% of that outside. Also, his report stated that most household dust is outdoor dust that is transported into the house, and that only a small percentage is developed from sources within. He then concluded that 80% of the indoor dust is identical in contaminant content to outdoor soil. Refinements to the concentration of contaminants on indoor versus outdoor dust should have a minor effect on exposure estimates. A similar trend is assumed for air-borne vapor phase concentrations. For this reason, differences between indoor and outdoor concentrations are not specifically considered, or equivalently, no distinctions are made for outdoor and indoor air quality.

2.7.3. Water Ingestion

The water ingestion rate of 2 L/day has been traditionally assumed for exposure through drinking water. However, EPA (1997a), after review of several literature sources, concludes that 2 L/day may be more appropriately described as a 84% value, or a value for high end exposure estimates (the 90% value was actually calculated to be 2.34 L/day). For this reason, a water ingestion rate of 2 L/day is assumed only for the high end exposure estimates. Since the high end scenario includes a farm and the farming family, it is also argued that farm labor requirements justify the higher rate of water ingestion. EPA (1997a) recommends a rate of 1.4 L/day as representative of average adult tap water drinking water consumption. This is the rate used for central scenarios in Chapter 5. The difference in central and high end tendencies is also modeled using the contact fraction. Again, this fraction is based on the time spent at home. The value of 0.70 is used to model the central estimate, for the residence setting, and the value of 0.90 is used to model the high end estimate, for the farm setting.

2.7.4. Ingestion of Terrestrial Food Products

This section discusses the consumption rates used in the beef, dairy, chicken, eggs, and vegetables/fruits ingestion pathways. All these pathways are similar in that the food products originate from the land. The high end demonstration scenario in Chapter 5 is a farming family which home produces a portion of its beef consumption. In site-specific assessments, home production of foods is often a scenario of concern, particularly if the home producers are located near the source of contaminant release. An exposure pattern similar to home production/consumption of foods is the consumption of locally produced foods. This would be relevant for individuals who live in a setting where food is produced, a rural setting for example, who do not produce any of their own food but who rely on local foods, such as from farmer's markets.

In order to estimate the contact rates for consumption of home produced foods, analysis of the USDA National Food Consumption Survey (abbreviated NFCS; USDA, 1992) of 1987-88 as conducted in EPA (1997a) will be used in this dioxin exposure reassessment. Specifically, EPA (1997a) used the household component of this survey. This component collects information over a 7-day period on the socioeconomic and demographic characteristics of households, and the types, values, and sources of foods consumed. Like the use of any survey data, use of this data must be understood by users. EPA (1997a) took from the household survey this information: 1) whether or not the food product was used in the house that week, 2) whether or not the food product used that week was home produced, 3) the quantity (mass, such as pounds or kilograms) of food consumed (home produced or not) in the house that week, 4) the number, age, and body weight of individuals in the household, and 5) the number of weekly meals consumed by each family member. If the household reported consumption that week, than EPA could calculate an individual consumption rate for “consumers only”. To do this, EPA (1997a) then assumed that all individuals in the household consumed some of the product, and the amount of individual consumption was based on average serving sizes for each individual (different as a function of the age of the individual) and number of meals consumed by each individual. Then, dividing by 7 (as in days of the week) and the body weights of the individuals, they derived consumer only consumption rates in terms of g/kg/d.

EPA (1997a) also looked at a second major USDA food consumption survey - the Continuing Survey of Food Intakes by Individuals (CSFII). This measured the food consumption patterns of all individuals throughout a 3-day period, whether the food was eaten at home or not, and did not have questions on home production practices. EPA (1997a) used this survey to derive general population per capita consumption rates (see next paragraph for definition of per capita).

In order to understand how the EPA (1997a) analysis of USDA data was used for this dioxin exposure document, it is important first to understand three types of generic food consumption rates: *1) Per Capita Consumption Rate*: This is an average consumption rate and includes all consumers as well as nonconsumers. *2) Consumption Rate for Consumers Only:* This is the consumption rate calculated only for individuals who report consumption of the food product in question. A per capita consumption rate can be calculated as a product of the consumption rate for consumers only and the ratio of those reporting consumption and all respondents including those who reported consumption plus those who didn’t report consumption (or equivalently, reported nonconsumption):

$$C_{pc} = C_{co} \frac{N_c}{N_c + N_{nc}} \qquad (2\text{-}10)$$

where C_{pc} is the per capita consumption rate, C_{co} is the consumer only consumption rate, N_c is the number of consumers, and N_{nc} is the number of non-consumers, and *3) Consumption rates, Per Capita or Consumer Only, for Consumers of Home Produced Products:* Home producers/consumers are a critical subpopulation, as noted earlier. EPA (1997a) was able to estimate consumer only consumption rates for home producers/consumers for a variety of food products from the household survey of the NFCS. These consumer only home producer/consumer rates are used in the demonstrations of Chapter 5.

The use of the consumer only consumption rate for home produced foods from the household survey of the USDA NFCS represents a significant departure from earlier versions of the dioxin exposure reassessments (EPA, 1992c; EPA, 1994a). It is the most appropriate type of rate to use when the scenario is a farm where individuals consume the food they produce - that is precisely what the definition of these rates are. Unlike earlier consumption rates, body weights are not used as the consumption rates are derived over the range of individuals including infants and children. It is also important to note that the consumer only consumption rates for the food products appear significantly higher than other consumption rates generated in EPA (1997a). For example, the general population per capita consumption rate for beef using the CSFII was 0.83 g/kg-day. The consumer only consumption rate for home produced beef was 2.45 g/kg/day. The following describes some of the differences in these two beef ingestion rates, 0.83 and 2.45 g/kg/day:

1) The household survey reports on total food product brought into the household, and this data is used directly for the calculation of consumers only consumption rates in EPA (1997a). Their calculation does not include bone and other wastage, trimmable fat, cooking loss, or uneaten foods. By contrast, intake rates developed from data in the 1-day individual consumption survey are defined “as eaten” meaning that these rates do account for cooking loss, wastage, and uneaten food. As will be described below, cooking and post cooking losses will be accounted for the meat product consumption rates developed from household data. The appropriate factor for beef is calculated to be 0.55. While the household data does not account for cooking and post cooking loss (without the correction introduced below), it does not include food eaten away from home, which could lead to underestimation of total consumption rates.

2) The 0.83 g/kg/day rate derived from the CSFII is a per capita consumption, meaning that it is calculated considering non-consumers as well as consumers. The percent consuming beef,

according to the CSFII, is 91%. Therfore, solving for the consumers only rate, using Equation (2-8) above, is 0.91 g/kg/day (0.83 g/kg/day divided by 0.91).

3) It is likely that home producing consumers - ie., only those who reported eating home produced beef which is what the 2.45 g/kg-day rate is - eat a fair amount of their home-produced beef during the weeks in which they reported this behavior. Other weeks they may also eat beef that was not home produced, but it might be smaller amounts so that their overall consumption rate of meat is likely to be lower than is reflected in these home producing consumers only rates. No data was available in EPA (1997a) to evaluate this speculation, but it seems reasonable (isn't it true that when the tomatoes in the home garden are ripe, the family will eat more fresh salad than usual?).

4) Two other differences between the CSFII and the household component of the NFCS which could lead to over or underestimation of actual behaviors include three-day versus week-long information (unclear which direction this would lead to) and individual recall versus head of household recall (again unclear).

To account for cooking and post cooking losses for the meat products which are home produced, information was obtained from USDA (1975). This data is summarized in Table 2-2.

This assessment uses the home producing consumers only consumption rate for home produced beef, milk, chicken, eggs, vegetables, and fruits. The following section describes how the "contact fraction" for these consumption rates is calculated. As has been defined, this describes the fraction of total food category consumption which is home produced. Following a description of this parameter for the dioxin reassessment, sections will describe the derivation of consumers only consumption rates for the various food products.

2.7.4.1. *Derivation of the Contact Fractions for Beef, Milk, Chicken, Eggs, Vegetables, and Fruits*

The home producer consumer-only consumption rate needs to be adjusted downward by consideration of the contact fraction. The average "consumer only" consumption rate for home producers developed from NFCS data will include weeks where only a little of the product in question is eaten and weeks when much of the product is eaten. Most importantly, however, this calculated "average" will only be an average during which consumption of home produced foods actually occurs. It is probably not reasonable to assume that average consumption weeks occur

52 weeks a year; there will be weeks where no consumption of the home produced product occurs. In other words, the contact fraction, or CF, will be less than 1.00.

Means to assign values to CF for site-specific applications will require judgement on the part of assessors. If localized information is available for a site-specific assessment, this could be used. For example, climate or local agronomic practices could assist in the assignment of a CF. One could assume, for example, that home production of dairy does not occur from December through February (13 weeks), and use this information to reduce the consumers only dairy consumption by 25% (13 weeks/52 weeks); i.e., the CF = 0.75. This assumes that a home producer of dairy products is producing at least some dairy during all weeks between February and December. EPA (1997a) did break out the household consumption survey data into seasons and it is clear that there was less consumption of home-produced food products during the winter as compared to the summer. But what is still true regardless of any refinement of this type is that the consumers only analysis of the USDA household survey is still only a reporting of households which did consume during the week.

EPA (1997a) developed data from the NFCS which will be used to assign values of CF for home produced foods. Based on questionnaire responses, EPA (1997a) was able to determine the fractions of total food intake that is home-produced; that is, of all the food product consumed by respondents in the survey, what fraction of that product was home-produced. For example, 3.8% of all beef consumed is home produced. This 3.8% includes, however, both those who raise cattle and then consume it (actual home producers) and those who took part in the survey, but did not raise any animals. Therefore, this 3.8% is not what is needed for current purposes. What is instead needed is the percentage (or fraction) of total beef consumed by people who raise cattle, that comes from their own stock. This could not be ascertained perfectly from the household survey because there was not this direct a question: “Knowing that you raise cattle, what percent of your home consumption is from your own stock?” Still, there were questions that were asked that are close to this. There was the question, “During the past year (1986), did anyone in the household produce any animal products such as milk, eggs, meat, or poultry for home use in your household?” The households which answered yes to this question form the universe of home producers of animal food products. These individuals were also asked questions about whether they consumed home-produced foods the week of the survey. For beef, 48% of households in this universe of home producers said that they did eat home-produced beef that week, while 52% said they did not. Therefore, 0.48 becomes the contact fraction for beef. Other contact fractions that were ascertained using this intersection of questions include: for diary - 0.21, for poultry - 0.15, and for eggs - 0.21. For fruits and vegetables, the universe of home producers was ascertained by those who answered yes to the question of whether there was gardening in the household. Responses of yes for consumption that week of the category "exposed vegetables" - 0.233, and "root vegetables" - 0.106, was averaged to yield a 0.17 that is used in this assessment as the CF for vegetables. The CF for fruits in this assessment is 0.12, based on a yes response to consumption that week of home produced "exposed fruits".

2.7.4.2. *Beef Ingestion*

The high end farming scenarios include this pathway for purposes of demonstration. Other terrestrial animal consumption pathways are demonstrated separately. EPA (1997a) calculated a consumers only overall (over all ages and regions of the US) average consumption rate for home produced beef of 2.45 g/kg/day. Applying the CF of 0.478 for beef as described above leads to an average consumption rate for home produced beef of 1.17 g/kg/day. This is further adjusted with the use of a preparation term. As shown in Table 2-2, the percent losses during cooking and after cooking is 27 and 24%, respectively. Therefore, the average consumption rate with these considerations is now estimated as, 1.17 g/kg/day * 0.73 * 0.76 = 0.65 g/kg/day.

Consumption rates of terrestrial animal food products are expressed in terms of fat ingested per day for two reasons. One, dioxin-like compounds tend to partition strongly toward lipids and virtually all of such compounds will be found in the fat portion of animal food products. Two, the algorithms to estimate concentrations in these food products estimated fat concentrations and not whole product concentrations. EPA (1997a) reports that USDA's Agricultural Handbook Number 8 (USDA, 1979-1984) lists the fat content of cooked beef, including lean and fat, as 21.54. This will be rounded to 22% in this assessment. Therefore, the ingestion of beef fat for individuals in the high end farming scenarios of Chapter 5 will be 0.143 g/kg/day (0.65 * 0.22).

2.7.4.3. *Dairy Ingestion*

As noted above, this pathway will be demonstrated in Chapter 5, but outside of any defined scenario. EPA (1997a) calculated a consumers only overall average consumption rate for home produced dairy of 14.0 g/kg/day. Applying the CF of 0.207 for dairy as described above leads to a final long term consumption rate of 2.90 g/kg/day. EPA (1997a) reports that USDA's Agricultural Handbook Number 8 (USDA, 1979-1984) lists the fat content of whole milk of 3.16. This will be rounded to 3% in this assessment. Therefore, the ingestion of dairy fat for this pathway demonstrated in Chapter 5 will be 0.087 g/kg/day.

2.7.4.4. *Chicken Ingestion*

Like the diary ingestion pathway, the chicken ingestion pathway will be demonstrated outside of a defined scenario. Furthermore, it will be assumed that the chickens are allowed to free range. A full discussion of predicting the concentration of dioxins in chickens and eggs, including free range chickens, is given in Chapter 4. EPA (1997a) calculates a consumers only consumption rate for home produced chickens of 1.57 g/kg/day. As described above, a CF of 0.151 will be adopted for home-produced chicken consumption leading to a total of 0.24 g/kg/day. As with beef, a preparation factor will be added, and as seen in Table 2-2, this factor will be equal to 0.70 * 0.70, or 0.49. The final consumption rate for chicken is estimated as 0.12 g/kg/day. EPA (1997a) reports that USDA's Agricultural Handbook Number 8 (USDA, 1979-1984) lists the fat content of meat and skin cooked chicken is 13.6. This will be rounded to 14% in this assessment. Therefore, the ingestion of chicken fat for this pathway demonstrated in Chapter 5 will be 0.010 g/kg/day.

2.7.4.5. *Egg Ingestion*

Like the diary and chicken ingestion pathways, the egg ingestion pathway will be demonstrated outside of a defined scenario. EPA (1997a) calculates a consumers only consumption rate for home produced eggs of 0.73 g/kg/day. As described above, a CF of 0.214 will be adopted for home-produced egg consumption leading to a total of 0.156 g/kg/day. EPA (1997a) reports that USDA's Agricultural Handbook Number 8 (USDA, 1979-1984) lists the fat content of eggs as 8.35%. This will be rounded to 8% in this assessment. This is the fat content of the entire egg, as the fat content of the yolk (which has all the egg fat) is about 30%. Therefore, the ingestion of egg fat for this pathway demonstrated in Chapter 5 will be 0.012 g/kg/day.

2.7.4.6. *Vegetable and Fruit Ingestion*

EPA (1997a) analyzed data from the NFCS household survey to estimate the amount of homegrown "exposed above ground vegetables/fruits" and "root vegetables". Protected vegetables/fruits, as opposed to exposed, were defined as vegetables/fruits which have outer protective coverings which are removed prior to consumption such as peas or oranges. No root vegetables were considered to be protected although, of course, it is common to consume some below ground vegetables such as carrots or potatoes after removal of the skin. The overall consumers only average of home grown fruits, above ground vegetables, and root vegetables was

1.49, 1.52, and 1.16 g/kg/d. These data are in fresh weight. These numbers were somewhat influenced by higher consumption rates for younger children of lesser body weight, as the consumption rate for three age ranges less than 5.0 ranged from 1.28 g/kg/day to 5.75 g/kg/day. The fruit and vegetable pathways will be included in both the central and high end scenarios of Chapter 5, and it will be assumed that the behaviors in the central and high end scenarios do not differ. The CF for both above and below ground vegetables will be 0.173 and for fruit (above ground only) will be 0.101, leading to final fresh weight consumption rates of 0.15 g/kg-day for fruit, 0.26 g/kg-day for above ground vegetables, and 0.20 g/kg-day for below ground vegetables.

2.7.5. Fish Ingestion

The procedure to estimate exposure to fish from consumption of fish caught in recreational pursuit will be different than that of the terrestrial food products. This is done because it is most common in exposure assessments to model exposure to fish in terms of a g/day consumption rate rather than a g/kg/day rate, and a wealth of data in the g/day format has been generated from consumption and creel surveys. Therefore, the LADD equation will be used with a separate consumption rate in g/day and an assumed body weight of 70 kg.

EPA (1997a) extensively reviewed the literature on fish consumption. Their analysis of available surveys led them to make recommendations on studies which they considered valid for generation of fish consumption rates. They also categorized available consumption rates from these surveys into: 1) General Population, 2) Recreational Marine Anglers, 3) Recreational Freshwater Anglers, and 4) Native American Freshwater Anglers.

The demonstration scenarios of Chapter 5 assume a rural setting which includes farms and non-farm residents. Also, it is assumed that a major river system cuts through the watershed which is used for recreational fishing and drinking. It is assumed to be a freshwater system, and therefore, the “recreational freshwater angler” consumption rates will be used in this assessment. Three studies were deemed valid for characterizing recreational freshwater angler consumption rates, and these include the mailed questionnaire studies of Ebert et al. (1993) and West, et al. (1989) and the diary study of Connelly, et al. (1996). The arithmetic mean consumption rate from these four studies are 5, 12, 17, and 5, respectively. The 95^{th} percentile consumption rates from these studies were 13 (Ebert et al, 1993) , 39 (West, et al., 1989), and 18 g/day (from Connelly, et al., 1996). From these data, EPA (1997a) recommended a mean and a 95^{th} percentile value for recreational anglers of 8 and 25 g/day. The central scenarios including a fish consumption pathway will assume the 8 g/day rate. The high end scenarios, which were defined as a subsistence beef farm, will not include a fish consumption pathway. This is done for demonstration purposes - it certainly is plausible for a farming family to partake in recreational fishing. A high end fish consumption pathway will be demonstrated outside of a scenario, however, as with other pathways. The high end pathway demonstration will use the 25 g/day rate as recommended in EPA (1997a).

It should be noted that these consumption rates are for all recreational freshwater fishers, not only those who consumed the fish they caught. Therefore, they could be underestimates for the purposes here - modeling individuals who consume fish they reacreationally catch. It is also noted that these rates are probably best described as, "as eaten" since the respondents were asked to estimate the weight of the fish they consumed, and assistance the respondents were given (choices, photos, etc.) were based on as consumed weights by those conducting the surveys. Because these rates are, "as eaten", there is no preparation factor required. Finally, it is assumed that the fish is 7% lipid. There were no specific recommendations in EPA (1997a) regarding this factor; there were tables showing the percent fat for various fish species. The 7% value selected appears to be a reasonable mid-range from those tables, and it was also the percent assumed in previous versions of this dioxin exposure assessment (EPA, 1994a).

As a point of comparison, the general population recommended mean consumption rate was 20.1 g/day (14.1 marine fish and 6.0 freshwater/estuarine fish). The 95th percentile recommended rate was 63 g/day. These were described as long term average consumption rates. For a Native American subsistence population, EPA (1997a) recommends a value of 70 g/day for mean intake of fish, and 170 g/day for the 95th percentile intake.

The current Exposure Factors Handbook (EPA, 1997a) and its predecessor (EPA, 1989) both emphasize the importance of obtaining site-specific information on the exposure parameters, not the least of which is the fish consumption rate. For smaller water bodies, EPA (1989) recommends that surveys of local fisherman would obtain the most appropriate fish consumption information. Alternately, EPA (1989) recommends using judgement regarding how many fish meals per year an individual could obtain from the contaminated waters and assuming meal sizes of 100 to 200 g. This was the approach adopted in the earlier draft of the Dioxin Exposure Assessment document (EPA, 1994a). With that approach, it was assumed that a "central" pattern of consumption of fish from an impacted water body led to 3 meals/person/year, and that a "high end" pattern led to 10 fish meals/person/year. With a meal size of 150 g (the current Exposure Factors Handbook recommends a mean fish meal size of 129 g, and a 95th percentile fish meal size of 326 g), this led to consumption rates of 1.2 g/day as the central estimate and 4.1 g/day as the high end estimate.

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Table 2-1. Summary of exposure pathway parameters selected for the demonstration scenarios of Chapter 5.

Pathway Description	Contact Rates		Contact Fractions	Comments
Soil Ingestion				Only pathway specific to an age-range; 2 to 6 year-old children assumed. Absorption fraction converts potential to absorbed dose for risk estimation.
Central	100 mg/d		1.0	
High End	600 mg/d		1.0	
Absorption fraction	0.30			
Soil Dermal Contact	Indoor	Outdoor		Unlike other pathways, daily contact is not assumed; approach instead estimates exposure in terms of contact/event * events/yr; central pattern based on behavior of non-farming adults, high end behavior based on farming pattern. Absorption fraction converts potential to absorbed dose for risk estimation.
Central			1.00	
CR, mg/cm^2-ev	0.005	0.03		
SA, cm^2	1,000	10,000		
EF, ev/day	1	0.27	1.00	
High End				
CR, mg/cm^2-ev	0.005	0.1		
SA, cm^2	1,000	3600		
EF, ev/day	1	0.96		
Absorption fraction	0.03	0.03		
Vapor/Dust Inhalation				Indoor/outdoor air quality assumed equal; central contact fraction is based on average at-home time from time use surveys
Central	13 m^3/day		0.70	
High End	20 m^3/day		0.90	
Water Ingestion				The more traditional 2.0 L/day was evaluated in EPA (1995) as an high end rather than a central value; 1.4 L/day recommended instead for central assumptions.
Central	1.4 L/day		0.70	
High End	2.0 L/day		0.90	

Table 2-1. (continued)

Pathway Description	Contact Rates	Contact Fractions	Comments
Terrestrial Food Products	All contact rates for the terrestrial food products, including animal food and vegetable/fruit, will be: 1) expressed in terms of g/kg/day thereby not requiring a 70 kg body assumption in the denominator of the LADD equation, and 2) based on the EPA (1997a) analysis of the household part of the USDA National Food Consumption Survey. Fish consumption will be handled in the more traditional way using a g/day fish consumption rate and an assumption of a 70 kg body weight. Central scenarios include fish pathway and veg/fruit ingestion pathway, but no other terrestrial food production; high end scenarios include beef/dairy and veg/fruit ingestion pathway, but no other food production including fish consumption. Chicken and egg pathways will be demonstrated outside the context of an exposure scenario.		
Beef Fat Ingestion Central High End	 NA 2.45 g whole/kg/d	 NA 0.478	2.45 g whole/kg/d is transformed to g fat/kg/d basis assuming 22% fat; additional factor of 0.55 accounts for cooking and post cooking loss
Milk Fat Ingestion Central High End	 NA 14.0 g whole/kg/d	 NA 0.207	14.0 g whole/kg/d is transformed to g fat/kg/d basis assuming 3% fat
Chicken Fat Ingestion Central High End	 NA 0.97 g whole/kg/d	 NA 0.151	0.97 g whole/kg/d is transformed to g fat/kg/d basis assuming 14% fat; additional factor of 0.49 accounts for cooking and post cooking loss
Egg Fat Ingestion Central High End	 NA 0.73 g whole/kg/d	 NA 0.214	0.73 g whole/kg/d is transformed to g fat/kg/d basis assuming 8% fat
Fruit Ingestion Above ground exp. Central High End	 1.47 g fresh/kg/d 1.47 g fresh/kg/d	 0.101 0.101	Central and high end behaviors assumed for residence and farm scenarios, respectively; difference is modeled with contact fractions only.

Table 2-1. (continued)

Pathway Description	Contact Rates	Contact Fractions	Comments
Vegetable Ingestion Above ground exp. Central High End Root vegetables Central High End	 1.52 g fresh/kg/d 1.52 g fresh/kg/d 1.16 g fresh/kg/d 1.16 g fresh/kg/d	 0.173 0.173 0.173 0.173	Central and high end behaviors assumed for residence and farm scenarios, respectively; both scenarios assume similar behaviors; differences are in other pathways and parameters.
Fish Ingestion Central High End	 8.0 g/day 25.0 g/day	 1.00 1.00	Based on "freshwater recreational angler surveys". Fat content is assumed to be 7%.
Exposure Duration, Body Weight, Lifetime: Based on mobility data (EPA, 1997a), a duration of 9 years was assumed for the central residence scenario, and a high end duration was assumed to be 30 years. The childhood soil ingestion pathway had a duration of 5 years. As noted above, a body weight assumption was not used for terrestrial food product pathways. For all others, a body weight of 70 kg was used except for childhood soil ingestion, which used a 17 kg body weight. In all cases, a 70 year lifetime was assumed.			

Table 2-2. Percent weight losses from preparation of various meats.

Meat Type	Mean Net Cooking Loss (%)[a]	Mean Net Post Cooking Loss (%)[b]
Beef	27	24
Chicken	30	30
Lamb	29	34
Pork	28	36
Turkey	31	28
Veal	30	25

[a] Includes dripping and volatile losses during cooking. Averaged over various cuts and preparation methods.
[b] Includes losses from cutting, shrinkage, excess fat, bones, scraps, and juices. Averaged over various cuts and preparation methods.
Source: USDA (1975).

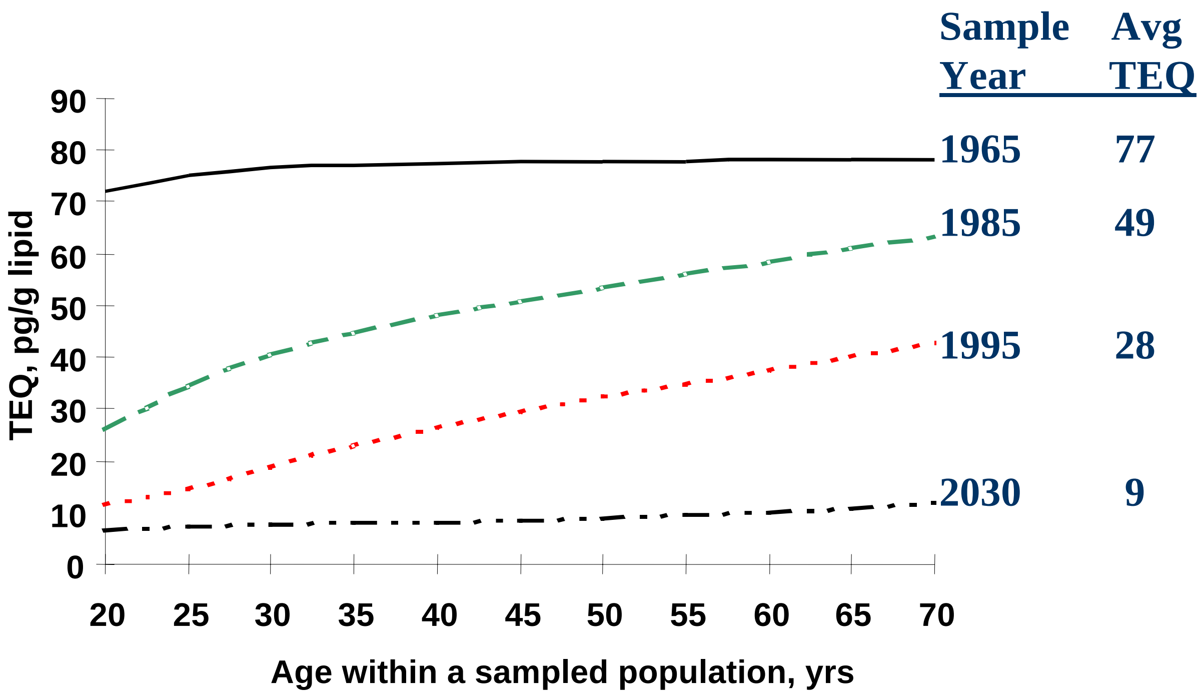

Figure 2-1. Predicted distributions of and average WHO_{98}-TEQ_{DF} concentrations within an adult population for four years: 1965, 1985, 1995, and 2030.

Source: Lorber (2002)