5. DEMONSTRATION OF METHODOLOGY

5.1. INTRODUCTION

This document has provided methodologies and background information for conducting site-specific exposure assessments for dioxin-like compounds. Chapter 2 summarized an overall exposure assessment framework, Chapter 3 described mechanisms of formation of dioxin-like compounds in stack emissions and the fate and transport modeling of releases from the stack to a site of exposure, and Chapter 4 provided methodologies to estimate exposure media concentrations for three sources of contamination, which were termed source categories.

The purpose of this chapter is to put all this information together and demonstrate the methodologies that have been developed. For this demonstration, exposure scenarios are developed which are associated with the three source categories. These categories were defined in Chapter 4, and are:

- **Soil Contamination**: The source of contamination is soil. The contaminated soil could occur at the site of exposure, such as in worker exposure scenarios at Superfund sites or contaminated soil at a residence, or the contaminated soil could occur distant from the site of exposure, such as a residence near a Superfund site.
- **Stack emissions:** Exposed individuals reside in the vicinity of the site where stack emissions occur and are exposed to resulting air-borne contaminants, and soil and vegetation on their property is impacted by deposition of contaminated particulates.
- **Effluent discharge:** A discharge of dioxin-like compounds in effluents impacts surface water and fish. Exposure occurs through consumption of the impacted fish and water.

An additional and important scenario is developed which merges the fate and transport algorithms of the soil contamination and emission source categories. This scenario is called, "background conditions". Further details on the structure and fate algorithms of the background conditions scenario are provided in Sections 5.3 through 5.5 below.

The demonstration in this chapter is structured around what are termed exposure scenarios. As defined in Chapter 2, an exposure scenario includes a description of the physical setting of the source of contamination and the site of exposure, behavior of exposed individuals, and exposure pathways. Chapter 2 also described the objective of exposure assessors to determine "central" and "high end" exposure scenarios. This objective was an important one for this demonstration, and the strategy to design such scenarios is detailed in Section 5.2 below.

For the soil contamination and the effluent discharge source categories, three dioxin-like compounds are demonstrated for each exposure scenario, including 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, and 2,3,3',4,4',5,5'-HPCB. For the stack emission source and the background conditions demonstrations, a different approach is taken with regard to compounds demonstrated. The 17 dioxin and furan compounds of non-zero toxicity are demonstrated; no dioxin-like PCBs are demonstrated. Exposure media concentration results are developed for all 17 congeners. As well, a "toxic equivalent" exposure media concentration, or TEQ concentration, is calculated as the sum of the individual congener concentrations multiplied the congener's Toxicity Equivalency Factor, or TEF.   As described in Chapter 1, TEQ concentrations are determined using the WHO 1998 scheme, and the TEQs of this chapter are therefore further identified as WHO_{98}-TEQ_{DF}. Final exposure estimates (Lifetime Average Daily Doses, or LADDs) are developed based on the WHO_{98}-TEQ_{DF} exposure media concentrations for these demonstrations.

Section 5.2 describes the strategy for development of the demonstration exposure scenarios. Section 5.3 gives a complete summary of the demonstration scenarios. Section 5.4 provides some detail on the example compounds demonstrated. Section 5.5 describes the source strength terms for the scenarios. Section 5.6 summarizes the results for all scenarios, which are exposure media concentrations for all exposure pathways, and exposure estimates which are Lifetime Average Daily Doses (LADDs) for all pathways. Also, several observations and additional analyses are provided in Section 5.6.

5.2. STRATEGIES FOR DEVISING EXPOSURE SCENARIOS

Chapter 2 of this document described procedures to assess individual exposures to known sources of contamination. Central and high end exposure patterns, and exposure parameters consistent with these definitions were proposed in that chapter. The demonstration in this chapter attempts to merge procedures for estimating individual exposures to known sources of contamination and current thoughts on devising central and high end exposure scenarios.

An exposure assessor's first task in determining patterns of exposure is to fully characterize the exposed population in relation to the source of contamination. If the extent of contamination can be characterized, then the exposed population would be limited to those within the geographically bounded area. An example of this situation might be an area impacted by stack emissions. Chapter 3 demonstrated the use of ISCST3 atmospheric dispersion model to predict ambient air concentrations and depositions rates for all points surrounding the stack.

Results listed in Tables 3-16 through 3-19 were only for the prevailing wind direction. As can be seen on these tables, the points of maximum impact were within 1 km of the stack. By overlaying the concentration isopleths onto a population density map, the exposed population can be identified. If the extent of contamination is not as clearly defined, such as extent of impact of nonpoint source pollution (impacts from use of agricultural pesticides, e.g.) or the compound is found ubiquitously without a clearly defined source, then the emphasis shifts from geographical bounding to understanding ambient concentrations, exposure pathways and patterns of behavior in general populations. The background conditions scenarios do, in fact, focus on the development of realistic ambient concentrations for its source strength terms.

After identifying the exposed population, the next task is to develop an understanding of the continuum of exposures. The exposures faced by the 10 percent of the population most exposed has been defined as high end exposures. Those faced by the middle of the continuum are called central exposures. Another important estimate of exposure level is a bounding exposure, which is defined as a level above that of the most exposed individual in a population. Arriving at such an understanding can be more of an art than a science. One consideration is the proximity of individuals within an exposed population to the source of contamination. For the incinerator example discussed above, one might begin an analysis by assuming that bounding or high end exposures occur within a kilometer from the stack, in the prevailing wind direction. Another important consideration is the relative contribution of different exposure pathways to an individual's total exposure. While individuals residing at this distance from the incinerator might experience the highest inhalation exposures, they may not experience other exposure pathways associated with contaminated soil on their property - such as consumption of home grown vegetables, dermal contact, or soil ingestion. Families with home gardens and individuals who regularly work in those gardens may reside over a kilometer from the incinerator and possibly be more exposed because of their behavior patterns. Screening tools, such as the algorithms of this assessment which are amenable to spreadsheet analysis (except for the ISCST3 modeling), can be used in an iterative mode to evaluate the interplay of such complex factors. When applied to a real world situation, information should be sought as to the makeup and behavior patterns of an exposed population.

The third principle task for evaluating impacts on an exposed population is to understand the relationship between impacts attributed to the source in question and the background exposures faced by the identified population. Assessors should attempt to answer the following question for dioxin-like compounds: What exposures to dioxin-like compounds would the identified populations have if the source in question were not in existence? The exposures faced by the identified in the absence of the source in question can be termed "background" or "cumulative" exposures; cumulative in two senses: that the exposures faced by the identified population result from the cumulative impacts of all sources in their environment and from all pathways. Chapter 2 describes approaches to determining background exposures to dioxin-like compounds, and this chapter demonstrates one way to evaluate background/cumulative exposures for a specific site.

The demonstration in this chapter attempts to be consistent with the goal of quantifying central and high end exposures, and properly considering background exposures. However, it is not exhaustive in its analysis, nor should it be construed as a case study with widely applicable results. All the scenario definitions, parameter values, and so on, were construed to be plausible and reasonable, and to demonstrate the application of a site-specific methodology, not to set any regulatory precedent.

Following are bullet summaries of key features of the structure and intent of the demonstrations.

- **Exposed populations:** Exposed individuals are assumed to reside in a rural setting. Exposures occur in the home environment, in contrast to the work environment or other environments away from home (parks, etc.). The presumption is made that the sources of contamination of this assessment can occur in rural settings in the United States. It is further assumed that the behavior patterns associated with the exposure pathways can exist in rural settings. Several of these behaviors characterized as high end relate to individuals on farms as compared to behaviors characterized as central for individuals not on farms. The exposed population for this demonstration, therefore, consists of rural individuals in farming and non-farming residences.
- **Plausibility of source strength terms:** The objective to determine plausible levels of source strength contamination was an important one for this demonstration. Sources demonstrated include small areas of soils with concentrations that have been found in industrial sites, stack emissions with emission rates typical of facilities containing state-of-the-art emission controls, and effluent discharges where characteristics of the effluent stream including rate of contaminant discharges were developed from recent data from pulp and paper

mills. Also, the background conditions scenarios include watershed soils and air concentrations which have been measured in an actual rural background setting. Section 5.5 describes the source terms in detail.

- **Proximity to sources of contamination:** The background scenarios use soil and air concentrations which have been measured in an actual background setting. Therefore, proximity to the source of contamination is not an issue. The effluent discharge source category is unique from the others in that soils or air are not impacted by the source. Only the surface water body into which the effluent is discharged is impacted. The only exposure pathways considered for this source category are drinking water and fish ingestion. Like the demonstration of background conditions, proximity is not an issue for this source category because the simple dilution model does not model fish and water concentrations as a function of distance from the source. It is felt that the water movement of a river or stream receiving the effluent discharge allows for sufficient mixing such that the simplistic dilution approach is reasonable for the dioxin-like compounds. As well, fish are not stationary so that a relationship between distance to source and where the fish are caught would be hard to develop or defend. Individuals in the effluent discharge demonstration simply exhibit behaviors associated with an impacted water body - they fish and they consume the water. Proximity to a stack emitting dioxin-like compounds was identified as an important determinant for identifying the continuum of exposures. Assuming there is a uniform distribution of exposure-related behaviors among exposed populations, i.e., their behavior patterns are not a function of where they live in relation to the stack, the most exposed individuals will be those exhibiting high end exposure behavior nearest the stack. This was the assumption made for purposes of this demonstration. A set of high end exposure behaviors and pathways were demonstrated for individuals residing 500 meters east of the stack, and a set of central exposure pathways were demonstrated for individuals residing 5000 meters east of the stack. The highest ambient air concentrations, and dry and wet deposition rates were simulated to occur at 200 to 1000 meters downwind, justifying 500 meters as an appropriate point for assuming high end impacts. Tables 3-16 through 3-19 listing concentrations and depositions rates as a function show that air concentrations and dry depositions rates at 5000 meters are only about half of what they are at 500 meters, although wet deposition rates are about 20 times higher at 500 meters as compared to 5000 meters. Without rigorous justification, the model output (concentrations and deposition rates) at 500 and 5000 meters was felt to appropriately characterize high end and central exposures. The site of contamination in the demonstration of the soil contamination source category is 10 acres in size and has concentrations that have been found in industrial sites. A working hypothesis is made that the population most exposed are those residing very near the site. Their soil is assumed to become contaminated over time due to the process of erosion; these processes normally do not carry contaminants long distances across land, particularly land developed with residences or where erosion is interrupted with ditches or surface water bodies. People from the surrounding community can be impacted by visiting or trespassing on the contaminated land, volatilized residues may reach their home environments, they may obtain water and fish from impacted water bodies, and so on. It seems reasonable to assume that those residing near these sites comprise the principally exposed individuals, or equivalently, the individuals experiencing the high end or bounding exposures associated with these areas of soil contamination. The soil contamination source category will be demonstrated with a single, high end scenario. The exposure site is assumed to be located 150 meters downgradient from the site of soil contamination.

- **Central and high end exposure patterns:** Chapter 2 described the exposure pathways that are considered in this methodology, and justified assignment of key exposure parameters (contact rates and contact fractions, exposure durations, and so on) as central or high end estimates. The bullet above discussing exposed populations indicated that several of the behavior assumptions were specific to individuals on farms, and that these behavior patterns were evaluated as "high end". "Central" behavior patterns were those for individuals residing in a non-farm residence. High end behaviors assumed to be different for individuals on farms versus central behaviors for individuals not on farms include, for example, residing on larger tracts of land (10 acres assumed for farmers; 1 acre assumed for non-farmers) and ingestion of home produced and impacted beef. Other patterns of behavior modeled as central and high end are not specifically associated with farming and not farming, but are assumed to be plausible for individuals in rural settings. These include home gardening for fruit and vegetables, inhalation exposures, children that ingest soil, and the use of impacted surface water bodies for drinking and fish to be ingested. Finally, a set of additional exposure pathways are modeled which are outside the scenarios altogether. These include the pathways of milk ingestion, chicken, and egg ingestion. Like the beef ingestion pathways, these pathways involve home production of the food products. Since an objective of the scenario development was to be realistic, it was felt that a scenario involving home production of the four animal food products: beef, milk, chicken, and eggs (not to mention fruits and vegetables), was highly unlikely. However, a scenario involving production of at least one animal terrestrial food product is more realistic.

- **Consideration of background exposures**: Background scenarios are devised which include the same exposure pathways and exposure parameters as the source-specific scenarios. The difference is that the exposure media concentrations are "background" or "cumulative" as contrasted to concentrations that result only from the source being modeled. Specifically, the background scenarios use, as input, "background" air and soil concentrations, and model all subsequent terrestrial and aquatic impacts. By structuring the background scenarios in this way, the key question, "What would be the exposure of individuals if the source in question did not exist?" is most specifically answered. Chapter 2 described a second approach to the issue of background exposures, and that was the comparison of source/scenario specific exposures to a generic background exposure. Volume II of this assessment has estimated that a general background exposure to WHO_{98}-TEQ_{DFP} is about 60 pg/day. One could, therefore, compare any source-specific estimates to this overall background estimate. Further detail on the specifics of the background scenarios is given below.
- **Realism of modeled concentrations:** The air and soil concentrations of the background scenarios are, by definition, realistic since they were derived from actual measured concentrations from a background site. For all other exposure media of the background scenarios, and in all other scenarios, the exposure media concentrations were modeled. The realism of modeled exposure media concentrations is dependent on the appropriateness of the models used for such estimations and the assignment of parameter values for those models. One way to arrive at a judgement as to the realism of estimated concentrations is to compare predictions with observations. To the extent possible (i.e., given the availability of appropriate data), model predictions of exposure media concentrations are

compared with occurrence data in Chapter 7, which describes several model validation exercises. As is shown, predictions fell within the realm of observed data. Chapter 4 describes the justification of all model parameter values. Many of the parameters are specific to the contaminants. Some contaminant properties were estimated as empirical functions of contaminant-specific parameters: the root concentration factor, RCF, was estimated as a function of the octanol water partition coefficient, Kow, for example. Other parameters were measured values, such as the vapor pressure or some of the bioconcentration factors. For non-contaminant parameters such as soil and sediment properties, patterns of cattle ingestion of soil (and other bioaccumulation/biotransfer parameters), and many others, selected values were carefully described and crafted to be plausible.

5.3. EXAMPLE EXPOSURE SCENARIOS

As noted above, all exposures occur in a rural setting. Exposure pathways were those which could be associated with places of residence in contrast to the work place or other places of exposure. The example scenarios are structured so that some (but not all) of the behaviors associated with high end exposures are included in the "high end" scenarios and all the central behaviors are in the scenarios characterized as "central". To summarize, the components which distinguished the high end exposure scenarios in contrast to the central scenarios include:

- Individuals in the central scenarios lived in their homes and were exposed to the source of contamination for only 9 years, in contrast to individuals in the high end scenarios, who were exposed for 30 years (except for the exposure pathway of soil ingestion, where the individuals are assumed to be children ages 2-6, and in both the central and high end scenarios, the exposure duration is 5 years).
- Individuals in the central scenarios lived on properties 1 acre in size, whereas individuals in the high end scenarios lived on properties 10 acres in size.
- Individuals in the high end scenario associated with the stack emission source category lived 500 meters from the incinerator, whereas individuals in central scenario lived 5000 meters from the incinerator.
- Individuals in high end scenarios obtained a portion of their beef from home-raised cattle stocks - such individuals are obviously farmers. Consumption of terrestrial animal food products were not assessed for non-farming rural individuals, representing the central scenarios.

- On the other hand, farming individuals in the high end scenarios were not assumed to recreationally fish. A fish pathway was included only in the central scenarios.
- Ninety percent of the inhaled air and ingested water by the high end individuals were assumed to be contaminated, whereas only 70% of these exposures were with impacted media for the central individuals. This is based on time at home versus time away from home assumptions for central versus high end individuals. Also, individuals in high end scenarios were assumed to consume 2.0 L/day of water and breathe 20 m^3/day of air as compared to 1.4 L/day and 13 m^3/day for individuals in central scenarios.
- Both the central and high end scenarios included a fruit/vegetable ingestion pathway. Although patterns of home production and consumption of fruits and vegetables differ within a population, average behaviors for individuals who home produce fruit and vegetables was assumed for both the central and high end scenarios in this assessment.
- The rates of ingestion of soil by children were higher for the high end individuals than the central individuals.

These are the distinguishing features for the central and high end exposure scenarios. For the sake of convenience mainly, all the scenarios defined below as high end are called "farms", and all central scenarios are called "residences". In addition to the scenarios, high end behaviors including fish, milk, chicken and egg consumption are separately modeled for the background conditions farm setting, the stack emission high end farm setting, and the soil contamination farm setting.

Again, the reason for separating these four pathways from the scenarios is that it is important for assessors to develop scenarios which combine a series of behaviors which are plausible to occur simultaneously in a real world setting. If such a strategy is followed, than the assessor is able to sum the exposures over all pathways to arrive at a total scenario exposure. It does not seem reasonably common in the real world that a single farm would include home production of several terrestrial animal food products (along with recreational fishing), which is why such a scenario is not developed in this assessment. In an exhaustive site-specific analysis, one might begin by evaluating all possible pathways, further evaluating pathways of most exposure, and then determining what pathways occur simultaneously for identified individuals in the exposed population. Only then can be the assessor begin to define a continuum of exposures.

The following bullets describe six exposure scenarios that are demonstrated. The numbering scheme and titles will be referenced for the remainder of this chapter:

Exposure Scenarios 1 and 2: Background conditions, Residence and Farm

Surface soils within the watershed are initialized to soil concentrations of the 17 dioxin-like congeners (no dioxin-like PCBs) which have been found in an actual rural setting. Also, air concentrations of the 17 congeners are initialized to air concentrations which have been found in this same rural setting. More details on this setting are provided in Section 5.5 below. Scenario 1 is the central residential scenario, and Scenario 2 is the high end farming scenario. Bottom sediment in a nearby river becomes impacted by long term erosion and atmospheric deposition. Water and fish in that stream are subsequently impacted. The exposure pathways for Scenario 1 are: water ingestion, air inhalation, fish ingestion, fruit/vegetable ingestion, soil dermal contact, and soil ingestion. The exposure pathways for Scenario 2 are: water ingestion, air inhalation, beef ingestion, fruit/vegetable ingestion, soil dermal contact, and soil ingestion. It is noted that for a background condition, it could be argued that all exposure is to background concentrations in exposure media. In other words, all contact fractions would be 1.00. However, if an assessor wished to compare the incremental impacts from a specific source of dioxin release with impacts an individual would receive by contact with the same exposure media which has only background concentrations of dioxins, than the assessor would assume all the same exposure behaviors (rates of contact, contact fractions). This demonstration takes this approach. When evaluating non-cancer risks using a margin-of-exposure approach, which is also demonstrated in this chapter, it is most appropriate, however, to compare incremental impacts with all background impacts, not only the same source-specific incremental impacts. This is discussed in more detail in Section 5.7, which demonstrates cancer and non-cancer risk assessments.

Exposure Scenario 3: Soil Contamination, Farm

A 40,000 m^2 rural farm is located 150 m (500 ft roughly) from a 40,000 m^2 area of bare soil contamination; an area that might be typical of contaminated industrial property. The surface soil at this property is contaminated with three example dioxin-like compounds to the same concentration of 1 part per billion (ppb). These compounds are: 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, and 2,3,3',4,4',5,5'-HPCB. The 1 ppb soil concentration is reasonable for industrial sites of contamination of dioxin-like compounds, and generally about three orders of magnitude higher than the concentrations of these congeners in background settings. As in the above and all scenarios, bottom sediment in a nearby river is impacted, which impacts the water and fish. The exposure pathways include: water ingestion, air inhalation, beef ingestion, fruit/vegetable ingestion, soil dermal contact, and soil ingestion.

Exposure Scenarios 4 and 5: Stack Emissions, Residence and Farm

A 4,000 m^2 rural residence (Scenario 4) is located 5000 meters from an incinerator, and a 40,000 m^2 (Scenario 5) rural farm is located 500 meters downwind from an incinerator. Emission data of the suite of 17 dioxin-like dioxin and furan congeners (no dioxin-like PCBs) is available from stack testing of an actual incinerator. This allows for estimation of impacts from each congener individually, and estimation of WHO_{98}-TEQ_{DF} impacts. The modeling of the transport of these contaminants from the stack to the site of exposure and other points in the watershed used the ISCST3 model. Details on the stack emission source for this demonstration and the ISCST3 model application are found in Chapter 3. A nearby impacted river provides drinking water and fish for recreational fishing. The exposure pathways for Scenario 4 are: water ingestion, air inhalation, fish ingestion, fruit/vegetable ingestion, soil dermal contact, and soil ingestion. The exposure pathways for Scenario 5 are: water ingestion, air inhalation, beef ingestion, fruit/vegetable ingestion, soil dermal contact, and soil ingestion.

Exposure Scenario 6: Effluent Discharge into a River

As has been discussed, this source category is different from others in that the air, soil, and vegetation at a site are not impacted. Rather, only surface water impacts are considered. Therefore, central and high end behaviors associated with places of residence are less pertinent for this source category. Exposure parameters associated with central behaviors for the water and fish ingestion pathways were chosen to demonstrate this source category. The source strength was developed from data on pulp and paper mill discharges of 2,3,7,8-TCDD; more detail on this source strength term development is provided in Section 5.5 below. The discharges of the other two example compounds are assumed to be the same for purposes of demonstration. Obviously, however, there is less of a tie to real data for the discharge rate for these other two example compounds. Also noteworthy for this source category as compared to the others is the size of the surface water body into which discharges occur. The other source categories all were demonstrated on water bodies with annual flow rates of $4.8 * 10^{11}$ L/yr. The river size into which the example effluent was discharged was developed from data from the 104 pulp and paper mill study (as discussed in Section 5.5 below). This river size was $4 * 10^{12}$ L/yr, one order of magnitude larger than the river of the other scenarios.

Food pathway analyses outside of the scenario framework: The food consumption pathways of fish, milk, chicken, and eggs are demonstrated using source strength characteristics of the three high end scenarios above: Scenarios 2 (background conditions), 3 (soil contamination), and 5 (stack emission). These food pathways were not modeled in the scenarios themselves. In these analyses, exposure media concentrations are calculated for each source and the pathway exposure estimates are provided. The purpose of these external pathway analyses was to provide further demonstration and to compare impacts from the various food pathways where methodologies have been provided in this assessment.

5.4. EXAMPLE COMPOUNDS

Three compounds were demonstrated for the soil contamination source and for the effluent discharge source category. For purposes of illustration, one compound was arbitrarily selected from each of the major classes of dioxin-like compounds. They are: 2,3,7,8-tetrachlorodibenzo-p-dioxin, 2,3,4,7,8-pentachlorodibenzofuran, and 2,3,3',4,4',5,5'-heptachloro-PCB. For the remainder of this chapter, these compounds will be abbreviated as 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, and 2,3,3',4,4',5,5'-HPCB.

These compounds demonstrate a range of expected results because of the variability of their key fate and transport parameters. The log octanol water partition coefficients (log Kow) for 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, and 2,3,3',4,4',5,5'-HPCB were 6.80, 6.50, and 7.71, respectively. Whereas the span of reported log Kow ranged from less than 6.00 to greater than 8.00, only a few reported values were at these extremes. Increasing log Kow translates to the following trends: tighter sorption to soils and sediments and less releases into air and water, less accumulation in plants and in cattle products (beef, milk), and more accumulation in fish. The Henry's Constants for the three compounds span the range of reported values, with the value of the PCB compound the highest of all reported at $6.6 * 10^{-5}$ atm-m^3/mole. There were few values less than the $4.98 * 10^{-6}$ atm-m^3/mole reported for 2,3,4,7,8-PCDF. Higher Henry's Constants translate to greater amounts of volatilization flux. The fate parameters for these three compounds and the 15 other dioxin and furan congeners are provided in Table 5-1.

For the background conditions and the stack emission demonstrations, Scenarios 1, 2, 4, and 5, a different approach was taken. All 17 of the dioxin-like dioxin and furan congeners were modeled. The ISCST3 modeling exercise described in Chapter 3 allowed for the generation of deposition amounts (wet and dry) and ambient air concentrations of all 17 congeners at sites of exposure for the demonstration of the stack emission source. For the background conditions demonstration, air concentrations were taken from an actual rural site (see Section 5.5). The dry depositions of particle-bound congeners were estimated as the particle-bound air concentration times a deposition velocity. Based on the measurements of Koester and Hites (1992), this deposition velocity was assumed to be 0.2 cm/sec. Also based on Koester and Hites (1992), who measured wet and dry deposition and showed these two quantities to be roughly equal for settings in Indiana, wet deposition was set equal to dry deposition.

The individual deposition rates and air concentrations for the 17 congeners in Scenarios 1, 2, 4, and 5 were used to model the exposure media concentrations for each congener individually with unique fate and bioaccumulation parameters. The exposure media concentrations include: air, soil, fruit/vegetables, water, fish, and the terrestrial animal food products including beef, milk, chicken, and eggs. A final WHO_{98}-TEQ_{DF} exposure media concentration was estimated using the 1998 WHO TEFs (Van der Berg, 1998):

$$C_{TEQ} = \Sigma \, TEF_i \, C_i \tag{5-1}$$

where:

C_{TEQ}	=	Toxic Equivalent concentration
TEF_i	=	Toxicity Equivalency Factor for congener i
C_i	=	concentration of congener i

The final results which are displayed for these scenarios are the WHO_{98}-TEQ_{DF} results only.

5.5. SOURCE TERMS

This section describes the source terms for the example scenarios. The source terms for the demonstration of background conditions, Scenarios 1 and 2, include both the initial air concentrations and the initial soil concentrations. The source terms for the soil contamination source demonstration, Scenario 3, include the area of contamination and soil concentrations. The source terms for the stack emission scenarios, 4 and 5, are the emission rates of contaminants from the stacks. These are described in Chapter 3. What will be detailed here, instead, are the deposition rates, air concentrations, and predicted soil concentrations at the site of exposure. In this way, scenarios 4 and 5 can be compared to the background scenarios, 1 and 2. The source term for the effluent discharge example scenario is the rate of discharge of dioxin-like compounds. This is briefly discussed in this section, with reference to a more detailed discussion in Chapter 7. Following now are discussions on these terms for all scenarios.

Scenarios 1 and 2

The 1994, the Ohio EPA (OEPA) conducted air monitoring in the city of Columbus in order to evaluate the impact of the Columbus Municipal Solid Waste Incinerator (MSWI). This incinerator operated between June, 1983 and December, 1994. Air samples were taken in March and April, 1994, at 6 sites in the city in Columbus and in a background site 28 miles southwest of Columbus. This background site is in the upwind direction from the facility. The air concentrations were higher in the urban air of Columbus as compared to the air concentrations in the background site: the average I-TEQ (I is short for "international"; see Chapter 1 for a discussion of the WHO TEFs versus the I TEFs) air concentration from 10 samples (6 sites, 2 sample dates, but only 5 sites sampled each sample date) in Columbus was 0.092 pg I-TEQ/m^3 as compared to 0.023 pg I-TEQ/m^3 from 2 samples (1 site, 2 sample dates) at the background site. The Ohio EPA visited these same sites in April, 1995, to measure air concentrations once the incinerator was no longer operating. The average air concentration from the 6 urban sites (all 6 sites sampled in 1995) was 0.046 pg I-TEQ/m^3 as compared to the background site of 0.018 pg/m^3. Further details on the 1994 sampling can be found in OEPA (1994) and details on the 1995 sampling can be found in OEPA (1995), and an overall summary of all sampling, including soil sampling, can be found in Lorber, et al. (1998). For the demonstration of background conditions, concentrations of the 17 dioxin-like congeners from the three sample dates at the rural site will be averaged to give the air concentration source terms.

The I-TEQ results discussed above were calculated assuming non-detects were equal to ½ the detection limit. Typically, non-detects are either assumed to be 0.0 or ½ detection limit. For TEQ concentrations, assumptions on the treatment of the detection limit can be an important issue if concentrations are consistently less than the detection limit and/or quantified concentrations are near the detection limit. For many samples of the OEPA sampling at Columbus, it turned out that I-TEQ concentrations did not differ significantly assuming non-detects equal 0.0 or non-detects equal ½ detection limit. For example, for the 10 Columbus samples in Mar/Apr of 1994, the average I-TEQ concentration would be 0.088 pg/m^3 at ND equal to 0.0 instead of 0.092 pg/m^3 at ½ detection limit. Likewise, for most of the congeners, the assumption on handling of non-detects is not critical as most of the samples were positively quantified, and/or the concentrations were sufficiently high such that assumptions on the values used for non-detects was not critical.

This was not the case, however, for 2,3,7,8-TCDD, the most toxic of congeners. For six sites and three sampling dates in the city of Columbus, or 16 data points (5 sites sampled for 2 dates, 6 sites sampled for one date), 6 were positive ranging from 0.0027 to 0.0262 pg/m^3. With non-detect equal to 0.0, the average of these 16 data points was 0.0048 pg/m^3; with non-detect equal to ½ detection limit, the average concentration was 0.0065 pg/m^3. Although seemingly small, this kind of difference can be important in the calculation of TEQ media concentrations. There were no positive occurrences of 2,3,7,8-TCDD in the three dates of sampling in the rural site.

The detection limit for 2,3,7,8-TCDD varied by sampling, but was always in the narrow range of 0.0043 to 0.0074 pg/m^3 at the rural site. At ½ the detection limit for the three rural samples, the 2,3,7,8-TCDD average concentration would be 0.0029 pg/m^3, but the range of possible concentrations would be 0.00 (ND=0) to 0.0058 pg/m^3 (ND= ½ DL).

An examination of the available quantified concentrations at the rural site and in Columbus suggests that assuming ½ detection limit for 2,3,7,8-TCDD would overestimate the air concentration of this congener in the rural site. Concentrations were more available for the penta dioxin congener, 1,2,3,7,8-PCDD, which are now examined to lend some insight about the difference in concentrations between Columbus and the rural site for the lower chlorinated congeners. To estimate the "true" 2,3,7,8-TCDD concentration, it will be assumed that the difference in the urban 1,2,3,7,8-PCDD concentration and the rural 1,2,3,7,8-PCDD concentration is assumed to be similar to the difference in the urban and rural 2,3,7,8-TCDD concentration. Of 16 samples of 1,2,3,7,8-PCDD in Columbus, 10 were quantified. The average concentrations at non-detect equal 0.0 and non-detect equal ½ detection limit for these 10 samples were 0.0151 and 0.0159 pg/m^3, respectively. One of 3 rural samples was quantified, leading to averages of 0.0037 and 0.0045 pg/m^3 at non-detect equal 0.0 and non-detect equal ½ detection limit. This would suggest that the rural concentration of 1,2,3,7,8-PCDD is about 1/4 that of the urban concentration (i.e., 0.0037/0.0151 = 0.245, and 0.0045/0.0159 = 0.28).

For 2,3,7,8-TCDD, where the urban concentration ranges from 0.0048 to 0.0065 pg/m^3, the "true" rural concentration is speculated to range from 0.0012 (0.0048/4) to 0.0016 (0.0065/4) pg/m^3, somewhat smaller than the 0.0029 pg/m^3 by the traditional non-detect equal to ½ detection limit method. For this example, the rural concentration of 2,3,7,8-TCDD will be assigned a value of 0.0014 pg/m^3, the midpoint of the hypothesized range.

All other air concentrations were calculated as the average of the three air samples, assuming ½ the detection limit for non-detects. The WHO_{98}-TEQ_{DF} air concentration for this profile was 0.021 pg/m^3.

In 1995, a soil sampling program was undertaken to evaluate the soils in the vicinity of the Columbus MSWI. This program was sponsored by the EPA with participation of the Agency for Toxic Substances Disease Registry (ATSDR), Ohio EPA and the Ohio Department of

Agriculture, and other state and local agencies. The purpose of the study was to determine whether the soils in the vicinity and also distant from the incinerator were impacted by the operation of the incinerator. Twenty-five samples were available for analysis, including 22 in the city of Columbus, and 3 in the same rural site 28 miles upwind of Columbus where air concentrations were taken. A full discussion of the soil sampling program can be found in EPA (1996), and an overview can be found in Lorber, et al. (1998).

This background scenario will, however, take advantage of the samples which were taken in the background setting. The soil concentration at the background site will be calculated as the average of the three background samples. The final WHO_{98}-TEQ_{DF} soil concentration for the background scenarios was 1.3 ppt. This soil sampling program took soil samples to a depth of 7.5 cm. Therefore, the concentrations as analyzed will be used to represent the "untilled" soil concentration. They will also be used to represent watershed soils for calculation of water body impacts. The question exists as to whether they should also be used to represent the tilled concentrations for the high end farming scenarios and for calculation of below ground vegetable concentrations. Brzuzy and Hites (1995) reported on the concentrations of dioxin in soil profiles from undisturbed background locations. Measuring the concentration in 2 cm increments, they generally found uniform concentrations to a depth of about 5 cm, with dropoffs thereafter. For two sandy soils, they found increasing concentrations which peaked at approximately 30 and 40 cm. Based on this information, the soil concentrations from the rural site used here will be divided by 2 to estimate tilled soil concentrations. A division by 3 to estimate the average concentration over the approximate 20 cm depth of the tilled soil depth for other scenarios in this assessment (stack emissions, soil contamination) would assume no dioxins exist below 7.5 cm in background soils. This was not found in the Brzuzy and Hites (1995) data. That is why the tilled concentration is calculated as the 7.5 cm concentration divided by 2.0 rather than 3.0. Recall that tilled soil concentrations are used to estimate concentrations in below ground vegetables, as well as in the dermal contact pathways, which assume gardening or farming as the cause for soil contact.

In summary, the background scenarios 1 and 2 use air concentrations averaged from three points in time and soil concentrations corresponding to the air samples from an actual rural setting.

It has been stated earlier in this chapter that the fate algorithms for this demonstration of background conditions would merge the fate and transport algorithms for the contaminated soil source with the stack emission source. In particular, the following will be done. First, deposition to soils will not be evaluated; soil concentrations will be supplied as source terms and are not assumed to change over the course of the time period of the demonstration, as in the soil contamination source category. In the same vein, air concentrations are not assumed to be impacted by soil emissions; the air concentrations will be assumed to be constant and supplied as source terms as in the stack emission source category. Above ground vegetative impacts will be evaluated given the estimated depositions of particle-bound dioxins and the transfer of vapor phase dioxins from the air profile. Below ground vegetative impacts will be based on soil-to-plant transfer algorithms assuming the tilled concentration supplied as a source term. Surface water impacts (water and fish) are a function of direct depositions of particle bound contaminants onto the water body and erosion from watershed soils. The soil concentration used for calculation of water body impacts will be the untilled soil concentration. Terrestrial animal food products are calculated as a function of above ground terrestrial vegetation (impacted only by air to plant transfers) and the initialized untilled soil concentrations.

Table 5-2 summarizes the source terms used for Scenarios 1 and 2, which include the deposition rates, the air concentrations, and the soil concentrations.

Scenario 3

This scenario was designed to be plausible for properties located near inactive industrial sites with contaminated soil. The selection of 1 µg/kg (ppb; or 1000 ppt) for the three compounds was based on 2,3,7,8-TCDD findings associated with the Dow Chemical site in Midland, MI (EPA, 1985; Nestrick, et al. 1986) as well as the 100 industrial sites evaluated in the National Dioxin Study (which included the Dow Chemical site; EPA, 1987). In that study, most of the sites studied had soil concentrations in the parts per billion range. The other key source information is the size of the contaminated area. This scenario will assume a contaminated site 40 hectares, or 40,000 m^2.

Scenarios 4 and 5

Chapter 3 described the application of the ISCST3 atmospheric dispersion model to estimate air-borne concentrations and deposition rates of the contaminants in the vicinity of the hypothetical incinerator, given contaminant emission rates in units of g/sec. As discussed in Chapter 3, the emission factors (mass compound emitted per mass feed material combusted) and resulting emission rates and concentrations (rate = mass compound emitted per time period and concentration = mass compound emitted per unit volume of air emitted) for all the congeners was typical of incinerators with a high level of air pollution control, e.g., scrubbers with fabric filters. The I-TEQ emission factor for the hypothetical incinerator, 4.5 ng I-TEQ/kg material combusted, was within a range of 0.3 ng I-TEQ/kg municipal solid waste incinerated, to 200 ng I-TEQ/kg hospital waste incinerated. This range was developed from representative test data for source-specific incinerators with a similar high level of pollution control technology. Two hundred metric tons per day of material was assumed to be incinerated at the hypothetical incinerator in order to arrive at emissions in appropriate units of g/sec. The TEQ emission rate was $1.5*10^{-9}$ g/sec. Wet and dry particle-bound deposition rates, in units of pg/m^2 -yr, were determined for all dioxins and furans, at various distances from the stack and in the prevailing wind direction. The exposure sites of Scenarios 4 and 5 are located downwind at 500 and 5000 meters, respectively, from the emission source. Other deposition rates needed for the stack emission source category were those used to estimate average watershed soil concentrations and direct deposition onto the impacted water body. For both the central and high end scenarios, rates of deposition at 5000 meters were used for these purposes. Since the watershed is 100,000 ha, which would be 10,000,000, meters long if it was square, assuming rates of deposition at 5000 meters might translate to an assumption that the stack was located relatively near the impacted water body.

Key source terms for Scenarios 4 and 5 are shown in Table 5-3. To facilitate comparison with the background scenarios, #1 and #2, these terms include the depositions, air concentrations, and soil concentrations.

Scenario 6

All key parameters used in Scenario 6 demonstrating the effluent discharge source category were developed using data associated with the 104 pulp and paper mill study (EPA, 1990). Derivation of the physical parameters including the flow rate of the receiving water body, flow rate of the effluent stream, suspended solids concentrations of the receiving water body and the effluent stream, and so on, are described in Section 4.5 of Chapter 4. An exercise evaluating the simple dilution model for predicting impacts to suspended solids in water body and subsequently to fish tissue concentrations resulting from discharges from these mills is described in Chapter 7. The bottom line conclusion from that exercise was that the simple dilution model appears to work satisfactorily for a screening model: predicted whole fish tissue concentrations for the majority of mills averaged about half as much as measured fish tissue concentrations. This could be due to an underestimate of the uncertain bioconcentration factor, BSAF, or it could be due to other factors. For the minority of mills, those with the highest volumes of receiving water, the model did not work as well. Predicted fish tissue concentrations were around an order of magnitude lower than measured concentrations. The precise reason for this discrepancy is not known, but the most likely explanation that larger water bodies have more uses and more sources of dioxin-like input - assuming that the fish tissue concentrations result singly from the mill discharge and a few proximate mills may be inappropriate.

Parameters for Scenario 6 were derived from the mills for which the model best performed. The average discharge rate from these mills was 0.197 mg 2,3,7,8-TCDD/hr. However, this data was valid for the time of sampling, which was 1988. Since then, pulp and paper mills have reduced the discharge of dioxin-like compounds in their effluents by altering the pulp bleaching processes. Gillespie (1992) reports that data on effluent quality from all 104 mills demonstrate reductions in discharges of 2,3,7,8-TCDD of 84% overall. On this basis, the discharge rate assumed for 2,3,7,8-TCDD was 0.0315 mg/hr (16% of 0.197 mg/hr). This same rate was assumed for the other two example compounds, although the claim is not being made that they are emitted by pulp and paper mills.

It is important to note that these discharge assignments are not intended to reflect current discharges of dioxin-like compounds from pulp and paper mills, even for 2,3,7,8-TCDD. Data from the 104-mill study did allow for development of a "composite" effluent discharger in certainly a plausible setting (receiving water body and discharge flow rates, suspended solids, etc.) for pulp and paper mills. Assigning what might be evaluated as a reasonable discharge rate of 2,3,7,8-TCDD from pulp and paper mills for current conditions allows for the example scenario to placed in some context, which was a primary objective of crafting all example scenarios. Individual sources must be evaluated on an individual basis.

In summary, the key source term for the demonstration of the effluent source category include a discharge rate of 0.0315 mg/hr for all three compounds demonstrated, and the discharge of this rate into a water body of size 4.65×10^9 L/yr.

5.6. RESULTS

The results of this exercise include the exposure media concentrations for all exposure pathways and scenarios, and the LADD exposure estimates. These two categories of results are summarized in Tables 5-4 through 5-10. Following now are several observations from this exercise. As a reminder for the background conditions scenarios, #1 and #2, and stack emission demonstration scenarios, #4 and #5, individual dioxin and furan congeners with non-zero toxic equivalency factors (TEFs) were modeled with unique fate and transport parameters until estimates of exposure media concentration were made. At that point, the WHO_{98}-TEQ_{DF} exposure media concentrations were estimated. For the sake of brevity, the WHO_{98}-TEQ_{DF} results are emphasized in this chapter.

It is important to understand that all observations made below are not general comments. Different results would arise from different source strength characteristics, proximity considerations, model parameter values, different models altogether, and so on. Chapters 6, 7, and 8 on User Considerations, Model Validation and Model Comparisons, and Uncertainty describes many areas of this assessment which should be considered when evaluating the methodology or viewing the results.

5.6.1. Observations Concerning Exposure Media Concentrations

Exposure media results are given in Tables 5-4 through 5-6.

● ***Soil Concentrations***:

1. The lowest exposure site soil concentrations resulted from deposition of particles 5000 m away from the example stack emission source. This was the location of the exposure site in the central stack emission demonstration scenario, Scenario 5. The highest exposure site soil concentrations were predicted for the demonstration of the soil contamination scenario. About 6 orders of magnitude separate the exposure site soil concentrations of 2,3,7,8-TCDD predicted for the central stack emission demonstration scenario, Scenario 4, and the soil contamination scenario, Scenario 5.

2. Concentrations for the stack emission central and high end scenario were about 3 and 2orders of magnitude lower than the central and high end scenarios demonstrating background conditions, respectively. This suggests that the example stack emission source, which was a single emission source with a high level of pollution control, would contribute little to overall background levels in soil.

3. The order of magnitude difference in distance from the stack between the central (5000 meters away) and high end (500 meters) scenarios is matched by the same order of magnitude difference in soil concentrations.

4. For both the background scenarios, 1 and 2, and the stack emission scenarios, 4 and 5, WHO_{98}-TEQ_{DF} soil concentrations were over an order of magnitude higher than 2,3,7,8-TCDD concentrations. The difference in 2,3,7,8-TCDD and WHO_{98}-TEQ_{DF} impacts to all media mirrors the difference in stack emissions of 2,3,7,8-TCDD and stack emissions of WHO_{98}-TEQ_{DF}. This

trend in differences between 2,3,7,8-TCDD and TEQ impacts occurs in all exposure media estimations for both the background scenarios and the stack emission scenarios.

5. For the demonstration of the soil contamination source, exposure site soil concentrations resulting from erosion were the same for all three compounds. This is because the same initial soil concentration was assumed at the site of contamination, and the erosion algorithm contains only one chemical specific parameter. This is the rate of dissipation for eroding contaminants. It was assigned a value of 0.0277 yr^{-1} (25-year half life) for all three example compounds. The stack emission source also has only one contaminant-specific parameter in the algorithm, the soil dissipation rate, and it was also assigned a value of 0.0277 yr^{-1} for all congeners.

- ***Vapor and Particle-Phase Air Concentrations***:

1. The partitioning of air-borne dioxins is modeled differently for the stack emission and the soil contamination sources. For the stack emission source, dioxins are assumed to be in equilibrium between the particle and the vapor phase from stack to receptor. The equilibrium partitioning model is explained in detail in Chapter 3. The application of this model in the demonstration scenario resulted in the 2,3,7,8-TCDD to be approximately 51% in the vapor phase and 49% in the particle phase. For the WHO_{98}-TEQ_{DF} air concentration, the partitioning, as seen in Table 5-4, is about 88% in the particle phase and 12% in the vapor phase for the background scenario, and about 71% particle/29% vapor for the stack emission source category. However, the modeling of dioxins above a site of soil contamination does not result in partitioning that approaches these equilibrium calculations. The volatilization, wind erosion, and dispersion algorithms are described in Chapter 4. As seen in Table 5-5, the vapor phase dominates the total air concentration and is about 95% of the total concentration. Residues which volatilize from the soil are assumed to remain in the vapor phase. However, it is possible that dioxin-like compounds released into the air this way would not remain in vapor phase, but would partly sorb to air-borne particles. An alternate approach to the one take for this assessment would be to sum the total concentrations of dioxins modeled to be emitted from soil, and to repartition them according to the equilibrium calculations. This is not done in this assessment.

2. The background WHO_{98}-TEQ_{DF} air concentration was 0.021 pg/m^3. In contrast, the WHO_{98}-TEQ_{DF} air concentration for the stack emission source was 2 orders of magnitude lower at 500

meters from the stack, at 0.00024 pg/m^3, and was over 2 orders of magnitude lower at 5000 meters from the stack, at 0.000085 pg/m^3.

3. The air concentration of 2,3,7,8-TCDD is highest in the soil contamination source category at 0.0042 pg/m^3. The background air concentration of this congener, used in Scenarios 1 and 2, is actually not that much lower at 0.0014 pg/m^3. There is the same 2 and 3 order of magnitude difference in the stack emission air concentrations of this congener compared to background that is seen in the comparison of other media concentrations - at 5000 m, the 2,3,7,8-TCDD concentration is $4.8*10^{-6}$ pg/m^3, and at 500 m, it is $1.4*10^{-5}$ pg/m^3.

4. The vapor phase air concentration over a site of soil contamination is a function of contaminant-specific parameters including the partition coefficient, Koc, and the Henry's Constant, H. As seen in Table 5-5, the vapor phase concentrations of the three demonstration congeners are different: 0.004 pg/m^3 for 2,3,7,8-TCDD, 0.007 pg/m^3 for 2,3,4,7,8-PCDF, and 0.002 pg/m^3 for 2,3,3',4,4',5,5'-HPCB. The particle phase concentrations were not different, however, since the wind erosion algorithm was not a function of contaminant specific properties.

- ***Water Impacts Including Water, Sediment, and Fish***:

1. There was a 2 order of magnitude difference in all water impacts between the background scenario and the stack emission scenario. This is easily seen in Table 5-4.

2. For the stack emission source category, surface water impacts were not a function of the location of the exposure site, unlike other media concentrations associated with the exposure site including air, soil, and home grown foods. Therefore, the media concentrations will be the same for the central and high end scenarios.

3. The surface water impacts are comparable for the contaminated soil demonstration, Scenario 3, the effluent discharge scenario, Scenario 6, and the background scenarios (#1 and #2). Examining the 2,3,7,8-TCDD fish lipid concentrations, they are: 6.4 ppt for the effluent discharge scenario, 4.3 ppt for the soil contamination scenario, and 3.0 ppt for the background scenarios. The surface water impacts are much lower for the stack emission scenarios, #4 and #5 - the fish lipid concentration is 0.0003 ppt for the stack emission scenarios. This observation is

particularly noteworthy in that the assumed effluent discharge rate is 84% lower than originally measured in the 104-mill study in 1989.

4. The PCB concentrations were between 1 and 2 orders of magnitude higher than the dioxin and furan because the key bioaccumulation variables estimating fish tissue concentrations, the Biota Sediment Accumulation Factor, BSAF, and the Biota Suspended Solids Accumulation Factor, BSSAF (used only for the effluent discharge source category), is 2.0 for the example PCB while it is 0.09 for the example dioxin and and 0.14 for the example furan.

5. Concentrations of WHO_{98}-TEQ_{DF} in water in the background and stack emission scenarios were all less than 0.01 pg/L (ppq), and for the individual congeners in the soil contamination and effluent discharge scenarios was less than 0.1 pg/L. These very low concentrations are the result of high lipophilicity of the dioxins, furans, and PCBs. The water ingestion pathway had the lowest exposure estimates of all pathways.

- ***Terrestrial Vegetation Concentrations***:

1. At first glance, there appears to be roughly a 2-3 order of magnitude difference in above ground vegetables/fruits and above ground leafy vegetation. In fact, this is due to two modeling differences: 1) the fruit/vegetable concentrations are presented in fresh weight. The dry weight to fresh weight conversion factor is 0.15, or equivalently, a dry weight concentration is about 6.7 times higher than fresh weight concentration, and 2) fruit/vegetables are bulky above ground vegetation. Literature data and experimental studies supported the hypothesis that dioxins impacted mainly the outer portions of bulky above ground vegetation and did not translocate to inner plant parts. The vapor phase air-to-plant algorithm, meanwhile, was calibrated to predict leafy vegetation, whole plant, concentrations. Therefore, to reduce predicted leafy whole plant concentrations to more appropriate dilute whole plant concentrations for bulky vegetation, an empirical parameter, VG_{ag}, was introduced. It was assigned a value of 0.01 for bulky above ground fruits/vegetables and 1.00 for leafy vegetation. With these two modeling differences, leafy vegetation dry weight concentrations are 666 times greater than bulky vegetable/fruit fresh weight concentrations. Other differences in concentrations are explained by differences in the particle phase impact algorithms of the two types of vegetation.

2. A more significant difference is found in the algorithms predicting below and above ground vegetation concentrations for the different source categories. Below ground vegetables are higher in concentration as compared to above ground vegetables, as seen in Tables 5-4, for the background and stack emission demonstrations, and in Table 5-5, for the soil contamination source category. However, the degree of difference is significantly more for the soil contamination source category as compared to the stack emission category or background demonstration scenarios. For these latter two cases, below ground vegetables are only between 1 and 2 times higher than above ground vegetables, but for the soil contamination source category demonstration, below ground vegetables are over 3 orders of magnitude higher than above ground vegetables.

The explanation for this trend is found in the air-to-soil model validation exercise which is described in Chapter 7. In that exercise, the background air profile used in the demonstrations in this chapter was modeled to deposit onto soil and mix in a 7.5-cm reservoir. The predicted soil concentrations were shown to match the measured soil concentrations, also used in the demonstrations in this chapter, reasonably well. Therefore, it would appear that the overall model seems to mimic air to soil relationships when air is the principal source of the dioxins in soil. Except for cases of specific soil contamination, this will often be the case, and certainly is expected to be case for background settings where there are no major sources for soil contamination. However, when the soil concentrations were assumed to be the source for air concentrations, and the soil contamination algorithms were used to predict air concentrations above the background soil, it was found that the predicted air concentrations were much lower than the measured air concentrations. Two possible explanations were offered for this trend: 1) the models predicting volatilization and dispersion were underpredicting air concentrations, and/or 2) measured air concentrations in the specific background setting used in the demonstration, and for background settings in general, are not only due to soil emissions, but also from the long range transport of residues from distant sources. In fact, it may be the case that distant sources of dioxin emissions to the air, such as stack emissions, followed by long range transport, explain significantly more of the background air concentrations found than local soil emissions from soils with background concentrations. If so, than a model prediction of background air concentration based on background soil emission will be significantly lower than background air concentrations.

For the purpose of this explanation, one can develop a ratio of air to soil concentration to more fully understand this difference. For the background scenario, and taking air and untilled soil concentrations from Table 5-4, an air to soil WHO_{98}-TEQ_{DF} concentration ratio is, 0.14 for the background scenario (total air concentration divided by untilled soil concentration, Table 5-4), 0.008 for the high end stack emission scenario, and 0.02 for the central stack emission scenario. The same ratio for the soil contamination scenario is on the order of $1*10^{-5}$. Therefore, the relative strength of air dioxins to soil dioxins is about three to four orders of magnitude higher when air is the source, as in the background scenarios, than when soil is the source, as in the soil contamination scenario.

Since above ground vegetables are a function of air concentrations, it then stands to reason that the discrepancy between below and above ground vegetables will be much higher when soil is the source of contamination as compared to when air is the source of contamination.

3. For the soil contamination demonstration, the tilled and untilled soil concentrations were the same for the three contaminants demonstrated. As noted in the observations for soil concentrations, this is because the parameters predicting exposure site soil concentrations from a distant site of soil contamination are the same for the three contaminants. However, there are differences in the predicted above and below ground vegetation for the three contaminants. Transfers from soil to plant are driven by chemical parameters, particularly the octanol water partition coefficient, Kow. 2,3,3',4,4',5,5'-HPCB and 2,3,7,8-TCDD had similar Kow, with 2,3,4,7,8-PCDF at a lower Kow. Higher Kow translates to tighter sorption to soil, and less transfer to plant, either through root uptake or air-to-leaf transfer. This trend translated to the lower fruit/vegetable concentrations for 2,3,3',4,4',5,5'-HPCB and 2,3,7,8-TCDD as compared to 2,3,4,7,8-PCDF.

- ***Terrestrial Animal Product Lipid Concentrations***:

1. Within each demonstration scenario, there appears to be a reasonably narrow range of predicted lipid concentrations among beef, milk, chicken, and egg fat. The difference is about a factor of 3 to 4. The lowest concentrations are noted for the stack emission demonstration scenarios, in the 10^{-3} to 10^{-2} pg WHO_{98}-TEQ_{DF}/g (ppt) range. The background concentrations were next highest, about two orders of magnitude higher in the 10^{-1} to 10^{0} ppt range, and the soil contamination demonstration was the highest at about two orders of magnitude higher still, at 10^{2} to 10^{3} pg 2,3,7,8-TCDD/g lipid.

2. The differences within a scenario can be explained by a combination of three factors: the apportioning of dry matter intake by the animal between soil and terrestrial vegetation, the

differences in the bioconcentration factors between beef/milk, chicken, and eggs, and the relationships between soil and vegetation as described above. For example, milk fat concentrations were lower than beef fat concentrations in all cases, but within about a factor of two. This was due to assumptions concerning apportioning of total dry matter intake between contaminated soil, contaminated pasture grass, and home-grown contaminated feeds. Beef cattle were assumed to take in twice as much soil as lactating cattle, 4% of their dry matter intake versus 2%, and much more leafy vegetation than lactating cattle, 48% pasture grass versus 8% pasture grass. Another interesting trend is that the chicken and egg fat concentrations are much higher than the beef/milk fat concentrations for the contaminated soil demonstration scenario, but the chicken and egg fat concentrations are lower or comparable for the background and stack emission scenarios. This is due to two factors: the free range chickens had 10% of their diet in soil as compared to 4 and 2% for beef and dairy cattle - this obviously will be important in a contaminated soil scenario, and the above ground vegetation were substantially less impacted, relatively speaking, in the soil contamination scenario as compared to the background or stack emission scenarios, as explained above in the vegetation observations. This would tend to minimize the importance of the vegetation in the diet of beef or dairy cattle in the soil contamination scenario.

3. In the observations concerning surface water impacts, it was noted that the fish lipid concentration of the PCB congener was much higher than the dioxin or furan congener. This was because the BSAF/BSSAF of the PCB congener was much higher at 2.10 as compared to the BSAF/BSSAF of the dioxin and furan congeners, 0.09 and 0.14, respectively. However, the literature suggests that the terrestrial animal bioconcentration factors are more similar for the three congeners. Hence, and as seen in Table 5-5, the beef, milk, chicken, and egg fat concentrations are comparable among the three congeners.

4. Table 5-6 shows the individual congener concentrations in beef for the high end background and stack emission scenarios. Recall that the TEQ beef concentration was about two orders of magnitude higher for the background as compared to the stack emission scenario. For all congeners except the tetra congeners, the difference is this same two order of magnitude difference, and up to 3 orders of magnitude difference for the higher chlorinated congeners. For the tetra congeners, 2,3,7,8-TCDD and 2,3,7,8-TCDF, the difference is an order of magnitude and less. This suggests that the congener profile in the hypothetical incinerator is distinctly

different than the background profile: the incinerator emissions would appear to have a greater proportion of emissions in the tetra congeners as compared to background air or soil.

5.6.2. Observations Concerning LADD Exposure Estimates

Much of the differences between exposure pathways and scenarios is due to differences in exposure media estimation. Therefore, much of the above discussion is also appropriate for analysis of Lifetime Average Daily Dose, LADD, estimates. What will be noted below are unique observations. LADD results are given in Tables 5-7 through 5-11.

1. Like in exposure media estimation, LADDs for the stack emission scenarios, 4 and 5, were the lowest at 10^{-11} to 10^{-7} ng WHO_{98}-TEQ_{DF}/kg-day, followed by the background scenarios, 1 and 2, at 10^{-8} to 10^{-5} ng/kg-day, the effluent discharge scenario which had a fish ingestion LADD in the 10^{-5} range, and finally the soil contamination scenario with the highest LADDs ranging from 10^{-8} to 10^{-3} ng/kg-day for all three compounds demonstrated - the dioxin, furan and PCB.

2. Tables 5-7 and 5-8 also show the percent of total scenario exposure which is accounted for by each pathway. The total scenario LADD was calculated simply as the sum of the pathway LADDs in the scenario, without accounting for any differences in body absorption. It should be remembered, however, that the amount of dioxin absorbed by the soil dermal contact pathway is estimated at 3%. This was accounted for in the calculation of LADD, so that the LADD for the soil dermal contact pathway was “absorbed” dose, while for all other pathways, the LADD was the “administered” or “potential” dose. As discussed in Chapter 2, the absorption for these other pathways was in the neighborhood of 80%, except for soil ingestion, where the absorption is on the order of 30%. Because of this 3% absorption accounted for in the dermal contact pathway, the LADD for this pathway is almost always the lowest of all pathways. From Tables 5-7 and 5-8, it is seen from the individual percentages that the food pathways dominate the scenarios, with fish ingestion dominating the central scenarios and beef ingestion dominating the high end scenarios. Furthermore, the beef ingestion pathway LADD was over an order of magnitude higher than the fish ingestion pathway LADD. This was more due to differences in the exposure parameters including the ingestion and contact rates, and the differences in the lipid content of the full product, rather than lipid concentrations themselves since the fish lipid concentrations tended to be higher than the beef lipid concentrations for a given source. For example, in the background scenario, the fish lipid concentration was modeled as 6.33 ppt WHO_{98}-TEQ_{DF}, while the beef lipid concentration was about one-fourth of that at 1.58 ppt WHO_{98}-TEQ_{DF}.

3. Differences between analogous "central" and "high end" exposure pathway estimates for the background demonstration scenarios, 1 and 2, were near or less than an order of magnitude (inhalation exposure for the central background scenario and the inhalation exposure for high end on-site scenario are analogous exposures). This is because the exposure parameters used to distinguish typical and high end exposures, the contact rates, contact fractions, and exposure durations, themselves did not differ significantly, and these were the only distinguishing features for analogous pathways in the background demonstrations. For the total exposure, however, there was a difference of a factor of 20 between high end and central exposure in the background demonstration scenarios. This is because the high end scenario included consumption of beef, which was the highest exposure pathway and exceeded the fish pathway of the central scenario by over an order of magnitude.

4. In the stack emission scenarios, placing exposed individuals either 500 or 5000 meters away from the incinerator did significantly impact the results. The order of magnitude difference in distance added about an order of magnitude difference in exposure media concentrations and hence LADD estimates. Therefore, the full difference in analogous pathways between the central and high end was closer to 2 orders of magnitude for the stack emission demonstration scenarios.

5. Tables 5-9 and 5-10 show results for the food ingestion pathways that were not included in the scenarios. One observation here is that the terrestrial animal product pathways, including milk, chicken, and egg ingestion pathways, are all less than the beef ingestion pathway, by up to an order of magnitude, despite the fact that the terrestrial food product lipid concentrations were fairly near each other. For example, the chicken fat concentration in the background scenario was 0.61 ppt WHO_{98}-TEQ_{DF}, compared to the beef fat concentration for that scenario of 1.58 ppt. The chicken ingestion pathway LADD was over an order of magnitude less than the beef ingestion pathway, however. This was due to the differences in the four other exposure related parameters which differ for chicken and beef: 1) beef was assumed to be 19% fat while chicken was assumed to be 13% fat, 2) the whole product ingestion rate of beef was 2.45 g/kg-day while the whole product ingestion rate of chicken was 0.97 g/kg-day, 3) according to the analysis of the National Food Consumption Survey described in Chapter 2, the beef ingestion pathway had a higher contact rate of 0.478 compared to the chicken contact rate of 0.151, and 4) the chicken and beef pathways had an additional food preparation factor which considers discarded portions

(bones, etc.) and cooking loss. This factor did not differ greatly for the two food products, 0.55 for beef and 0.49 for chicken.

6. Table 5-11 relates all the pathways considered in this demonstration for the background, the stack emission, and the soil contamination demonstrations. This table includes the food ingestion pathways that were not in the demonstration scenarios. It was constructed by assigning a value of 1.00 to the beef ingestion pathway, and then determining the ratio of the other pathways to the beef pathway. This table again shows the domination of beef and milk exposures, at least given the exposure parameters, lipid contents, and so on, assigned to the demonstration scenarios. The fish pathway was very important in the background scenario as compared to the other two scenarios. The main reason for this was how the models predicted bottom sediments. For the background scenario, the predicted sediment concentration was nearly three times higher at 3.4 ppt WHO_{98}-TEQ_{DF} than the soil to which the cattle were exposed, 1.3 ppt. In contrast, the sediment concentration was nearly an order of magnitude lower at 0.0024 ppt WHO_{98}-TEQ_{DF} than the soil concentration to which cattle were exposed in the high end stack emission scenario, at 0.035 ppt WHO_{98}-TEQ_{DF}. Even more dramatic, there was a two order of magnitude difference in the sediment and soil concentration for the soil contamination site scenario - 1.4 vs. 357 ppt 2,3,7,8-TCDD. Table 5-11 also shows that a childhood pattern of soil ingestion can be an important pathway, ranking along with chicken and egg exposures in the background and stack emission demonstrations. The chicken and egg pathways were considerably more important in the soil contamination scenario as compared to the other two pathways. This is due to the trend of predicting much higher chicken and egg concentrations in the soil contamination scenario as compared to the background and stack emission scenarios; this was discussed earlier in the observations for the exposure media concentrations. Vegetable ingestion was also more important in the soil contamination scenario, which was driven by high below ground vegetable concentration. Vegetable ingestion and inhalation were comparable to the chicken, egg, and soil ingestion pathways in the background and stack emission scenarios. Fruit ingestion, dermal exposure, and water ingestion are all relatively minor compared to the animal ingestion pathways and were less than 1% of the exposures estimated for beef ingestion.

7. Fish was the principal impacted media for the effluent discharge source category, with fish ingestion 19 times higher than water ingestion, the only two pathways considered for the effluent discharge category. Fish was an important route of exposure in the central scenarios for the

background and stack emission scenarios, 1 and 3, explaining over half of all exposures estimated for those scenarios.

5.7. HEALTH RISK DEMONSTRATIONS

Chapter 2 described the procedures to generate estimates of excess cancer risks and the ratio IOB to evaluate potential non-cancer impacts. This section will demonstrate these health risk assessment procedures, using the background and the high end stack emission scenarios.

Recall that excess cancer risk is estimated as the product of the LADD and cancer potency factor, q_1^*. For 2,3,7,8-TCDD, the q_1^* is 1.0 kg-day/ng, and this value is also used for TEQ LADDs. Table 5-12 shows the cancer risk estimates for the background and the stack emission high end scenarios, where LADDs are for WHO_{98}-TEQ_{DF} exposures.

As seen in Table 5-12, there is a 2 order of magnitude difference between the total cancer risk of both scenarios, the same 2 order of magnitude difference in the total LADDs as noted earlier. The cancer risk associated with the high end scenario for the incinerator was $9*10^{-7}$, while the background high end cancer risk was $9*10^{-5}$.

The cancer risk for the background scenario corresponds to a lifetime average daily dose, LADD, of 6 pg WHO_{98}-TEQ_{DF}/day. This is about a factor of seven lower than the background dose of 43 pg WHO_{98}-TEQ_{DF}/day generated in Volume II, Chapter 4 of the Exposure Reassessment Document. The reasons for this difference are: 1) the Volume II background exposure estimate was an average daily dose, ADD, not an LADD calculated in the demonstration scenarios here. The LADD estimated in this chapter assumes 30 years of exposure. The ADD during the exposure period would be just over twice, or 70/30, the LADD; 2) the Volume II background exposure considered additional pathways including fish, dairy ingestion (milk and otherwise), eggs, pork, and poultry. If one adds the additional pathways for the background high scenario - milk, chicken, egg, and fish shown in Table 5-9 - the LADD (and ADD) roughly doubles; 3) the exposure factors are different, with the most important difference being that in the exposure scenarios considered in this chapter, contact fractions of less than 1.0 were assumed - less than 0.5 for the terrestrial animal pathways, in fact.

Some of these differences also are relevant for the procedures demonstrated here to characterize non-cancer risk. Specifically, the procedures described in Chapter 2 require the assignment of a “background body burden” in the calculation of an Increment Over Background, IOB, ratio. The IOB is defined as the ratio of the incremental of body burden due to the source being evaluated (IBB) and the background body burden (BB_{bk}) times 100%. As described in Chapter 2, the BB_{bk} can be a generic U.S. background body burden, or a site-specific background.

The generic adult background body burden is currently evaluated as 5 ng WHO_{98}-TEQ_{DF}/kg. However, this quantity represents the full range of the current adult population; an assessor could 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. As well, one could develop a body burden that is specific to the site being evaluate. This could be a non-trivial exercise and could involve estimating quantities that have not been considered when evaluating only an increment of exposure due to a specific source. Chapter 2 went into some of the issues to consider when developing a site-specific estimate of background exposure dose/intake or background body burden.

If an assessor could determine an appropriate background exposure dose for a specific site being evaluated, he could then use the simple first order pharmacokinetic model to convert this site-specific dose to a site-specific BB_{bk}. To do so, an assessor needs to estimate the total exposure of an individual (or individuals) to dioxins as though the nearby source being evaluated was not in existence. In a farm family scenario, the family would still be consuming home produced foods, but these foods would only be impacted by background dioxins in the environment, and no longer by the source being evaluated. But they would also be consuming store-bought or restaurant-bought foods. The "total" exposure would include all pathways considered in the scenarios of this chapter, but other pathways as well.

For the purposes of this demonstration, it will be assumed that the farming family in the background scenario consumes foods at similar rates whether or not they are consuming home-produced or store-bought food products, and that their exposure is characterized by all the pathways in the formal scenarios of Table 5-7, as well as the additional scenarios shown in Table 5-9. To estimate their average background daily dose over a lifetime, the exposure duration will increase from 30 to 70 years, and the contact fractions will all rise to 1.00. The resulting daily exposure is 1.16 pg WHO_{98}-TEQ_{DF}/kg-day. This 1.16 pg WHO_{98}-TEQ_{DF}/kg-day will be used here as the "site-specific background dose" against which one can develop IOBs for the incinerator source.

For generation of the increment of body burden due to the incremental exposure, one needs to estimate the ADD during the period of exposure. The total LADD for the stack emission high end scenario, as displayed in Table 5-7, is $1.01 * 10^{-3}$ pg WHO_{98}-TEQ_{DF} /kg-day. The ADD can be simply calculated as this LADD times 70/30, or $2.36 * 10^{-3}$ pg WHO_{98}-TEQ_{DF}/kg-day. It is now possible to calculate the site-specific background body burden, BB_{bk}, and the increment of body burden due to the site-specific source, IBB, using this generalized equation:

$$BB_i = \frac{DD\ AF}{k\ CF_1}\ (1 - e^{-kt}) \qquad (5\text{-}2)$$

where:

BB_i	=	body burden of interest, either BB_{bk} or IBB, pg/g (ppt) whole weight basis
DD	=	dose quantity for calculating the BB, either the site-specific lifetime average daily dose, LADD, or the daily dose during the period of exposure to the specific source, ADD, pg/kg-day (whole body weight basis)
AF	=	absorption fraction
k	=	first-order rate of decline of dioxin residues from the body, day^{-1}, calculated as $(\ln 2/t_{1/2})$, where $t_{1/2}$ is the half-life, days
CF	=	conversion factor, 1000 g/kg
t	=	time of exposure, either lifetime for BB_{bk} or the exposure duration for ADD, days

Using assumptions used in the Risk Characterization as first approximations for pharmacokinetic modeling of TEQs, AF will be assumed to be 0.8, $t_{1/2}$ will be 7.1 years so that k is calculated as 0.000267 day^{-1}. The appropriate values for t include the exposure duration corresponding to the ADD described above for the high end scenario, which is 30 years (10950 days), and the 70 year (25550 days) lifetime assumed for calculation of BB_{bk}. Finally, the DDs equal the 1.16 and 0.00236 pg WHO_{98}-TEQ_{DF}/kg-day, as discussed above.

Substituting these values yields body burdens of 0.007 pg WHO_{98}-TEQ_{DF}/g for IBB and 3.5 pg WHO_{98}-TEQ_{DF}/g for BB_{bk}. The IOB is then easily solved for as, 0.2 % ([0.007/3.5]*100). This increment of body burden increase is very low and can probably be characterized as insignificant. It is also interesting to note that the BB_{bk} at 3.5 ppt TEQ is lower than the general US population background body burden of 5.0 ppt TEQ. As discussed in Volume II of these Exposure Documents, and as alluded to in discussions above, the general US population background body burden is influenced by higher concentrations in older individuals who experienced higher doses in the past. The "steady state" body burden at the current general US background exposure dose of 1.0 pg WHO_{98}-TEQ_{DFP}/kg-day is also lower than 5.0 ppt, at 3.0 ppt. The assessor can choose either the general US background exposure, this steady state exposure at current US background doses, a site-specific background exposure, or even another background quantity in developing the IBB term for non-cancer risk assessing at specific sites.

It is once again emphasized that the scenarios and all exposure parameters, and the fate modeling with their parameters, used in this demonstration chapter, are not being offered as default values or recommendations for all uses. Chapter 6 contains additional information pertaining to these models, including sensitivity analysis exercises and discussions of model parameters. Chapter 7 provides a critical evaluation of the fate models selected in this methodology, including model comparisons and model validation exercise. Chapter 8 on Uncertainty critically evaluates the fate and exposure modeling approaches and parameters used in this assessment. Information in these three Chapters should be reviewed when evaluating the validity of the approaches demonstrated in this Chapter.

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Table 5-1. Fate and transport parameters for the dioxin-like congeners demonstrated in this chapter (see bottom of table for column definitions).

Congeners	TEF	H	$p°_L$	V/P	Log Kow	Koc	Bvpa	BSAF/ BSSAF	RCF	BCF	CCF	ECF
2378-TCDD	1.0	$3.29*10^{-5}$	$6.27*10^{-10}$	51/49	6.80	$3.98*10^{6}$	$6.55*10^{4}$	0.090	5200	5.76	8.8	7.8
12378-PCDD	1.0	$2.60*10^{-6}$	$9.20*10^{-11}$	13/87	6.64	$2.69*10^{6}$	$2.39*10^{5}$	0.083	3916	5.55	6.8	6.0
123478-HxCDD	0.1	$1.07*10^{-5}$	$2.01*10^{-11}$	3/97	7.80	$3.89*10^{7}$	$5.20*10^{5}$	0.028	30600	2.69	3.6	5.4
123678-HxCDD	0.1	$1.10*10^{-5}$	$2.01*10^{-11}$	3/97	7.30	$1.23*10^{7}$	$5.20*10^{5}$	0.011	12600	2.32	5.6	10.2
123789-HxCDD	0.1	$1.10*10^{-5}$	$2.01*10^{-11}$	3/97	7.30	$1.23*10^{7}$	$5.20*10^{5}$	0.013	12600	2.99	2.4	4.5
1234678-HpCDD	0.01	$1.26*10^{-5}$	$5.05*10^{-12}$	1/99	8.00	$6.17*10^{7}$	$9.10*10^{5}$	0.003	43700	0.48	1.4	4.8
OCDD	0.0001	$6.75*10^{-6}$	$1.32*10^{-12}$	0.2/99.8	8.20	$9.77*10^{7}$	$2.36*10^{6}$	0.001	62200	0.69	0.3	4.3
2378-TCDF	0.1	$1.44*10^{-5}$	$6.80*10^{-10}$	47/53	6.10	$7.76*10^{5}$	$4.57*10^{4}$	0.072	1500	1.25	3.1	2.7
12378-PCDF	0.05	$5.00*10^{-6}$	$1.96*10^{-10}$	25/75	6.79	$3.80*10^{6}$	$9.75*10^{4}$	0.020	5110	0.97	18.0	20.5
23478-PCDF	0.5	$4.98*10^{-6}$	$1.15*10^{-10}$	16/84	6.50	$1.95*10^{6}$	$9.75*10^{4}$	0.144	3050	4.13	7.4	7.8
123478-HxCDF	0.1	$1.43*10^{-5}$	$4.21*10^{-11}$	7/93	7.00	$6.17*10^{6}$	$1.62*10^{5}$	0.007	7410	3.12	4.8	7.4
123678-HxCDF	0.1	$7.31*10^{-6}$	$4.21*10^{-11}$	7/93	7.00	$6.17*10^{6}$	$1.62*10^{5}$	0.017	7410	2.67	5.3	8.2
123789-HxCDF	0.1	$1.10*10^{-5}$	$2.56*10^{-11}$	4/96	7.00	$6.17*10^{6}$	$1.62*10^{5}$	0.060	7410	2.67	4.1	6.2
234678-HxCDF	0.1	$1.10*10^{-5}$	$2.56*10^{-11}$	4/96	7.00	$6.17*10^{6}$	$1.62*10^{5}$	0.057	7410	2.37	2.1	3.0
1234678-HpCDF	0.01	$1.41*10^{-5}$	$1.13*10^{-11}$	2/98	7.40	$1.55*10^{7}$	$8.30*10^{5}$	0.001	15100	0.55	1.0	3.1
1234789-HpCDF	0.01	$1.40*10^{-5}$	$6.51*10^{-12}$	1/99	8.00	$6.17*10^{7}$	$8.30*10^{5}$	0.035	43700	1.32	0.9	2.2
OCDF	0.0001	$1.88*10^{-6}$	$1.24*10^{-12}$	0.2/99.8	8.80	$3.89*10^{8}$	$2.28*10^{6}$	0.001	180000	0.27	0.3	1.4
233'44'55'-HPCB	0.0001	$6.60*10^{-5}$	$1.46*10^{-11}$	42/58	7.71	$3.16*10^{7}$	$1.49*10^{5}$	2.10	26100	2.30	6.5	7.4

Table 5-1. (con't.)

Definitions for Table 5-1:

TEF:	Toxicity Equivalency Factor	Log Kow:	log octanol water partition coefficient
H:	Henry's Constant, atm-m^3/mole	Koc:	Organic carbon partition coefficient, L/kg
$p°_L$:	liquid sub-cooled vapor pressure, 20°C, atm	B_{vpa}:	Air-to-leaf biotransfer factor, (pg PCDD/g leaf dry)/(pg PCDD/g air)
V/P:	Vapor phase/particle phase percentages	BSAF/BSSAF:	Biota-to-(suspended) sediment accumulation factor, unitless
RCF:	Root concentration factor, unitless	BCF/CCF/ECF:	Beef/milk, chicken, egg fat bioconcentration factor, unitless

Table 5-2. Summary of key source terms for the background scenarios, 1 and 2.

Congeners	TEF	Dry Dep, pg/m^2-yr	Wet Dep, pg/m^2-yr	C_{air}, pg/m^3	C_{soil}, pg/g
2378-TCDD	1.0	43	43	0.0014	0.37
12378-PCDD	1.0	286	286	0.0052	0.14
123478-HxCDD	0.1	482	482	0.0079	0.35
123678-HxCDD	0.1	570	570	0.0093	0.82
123789-HxCDD	0.1	826	826	0.0135	1.23
1234678-HpCDD	0.01	14,170	14,170	0.227	17.73
OCDD	0.0001	56,900	56,900	0.904	160.89
2378-TCDF	0.1	82	82	0.0028	0.64
12378-PCDF	0.05	308	308	0.0065	0.17
23478-PCDF	0.5	394	394	0.0074	0.21
123478-HxCDF	0.1	780	780	0.0133	0.15
123678-HxCDF	0.1	909	909	0.0155	0.11
123789-HxCDF	0.1	168	168	0.0028	0.15
234678-HxCDF	0.1	555	555	0.0092	0.64
1234678-HpCDF	0.01	4277	4277	0.0692	4.06
1234789-HpCDF	0.01	893	893	0.0143	0.27
OCDF	0.0001	4198	4198	0.0667	10.72
WHO_{98}-TEQ_{DF}		1180	1180	0.021	1.29

Table 5-3. Summary of key source terms for Scenarios 4 and 5, the stack emission demonstration scenarios.

Congeners	TEF	Scenario 4 - Central; 5000 meters downwind				Scenario 5 - High End; 500 meters downwind			
		Wet Dep pg/m^2-yr	Dry Dep pg/m^2-yr	C_{air}, pg/m^3	C_{soil}, pg/g	Wet Dep pg/-m^2-yr	Dry Dep pg/m^2-yr	C_{air} , pg/m^3	C_{soil}, pg/g
2378-TCDD	1.0	0.05	0.10	$4.84*10^{-6}$	$1.72*10^{-4}$	0.68	0.44	$1.37*10^{-5}$	$1.36*10^{-3}$
12378-PCDD	1.0	0.17	0.36	$1.01*10^{-5}$	$6.40*10^{-4}$	2.54	1.65	$2.87*10^{-5}$	$5.04*10^{-3}$
123478-HxCDD	0.1	0.25	0.52	$1.30*10^{-5}$	$9.22*10^{-4}$	3.66	2.38	$3.71*10^{-5}$	$7.27*10^{-3}$
123678-HxCDD	0.1	0.33	0.69	$1.72*10^{-5}$	$1.22*10^{-3}$	4.85	3.14	$4.89*10^{-5}$	$9.66*10^{-3}$
123789-HxCDD	0.1	0.36	0.75	$1.89*10^{-5}$	$1.34*10^{-3}$	5.33	3.46	$5.39*10^{-5}$	$1.06*10^{-2}$
1234678-HpCDD	0.01	3.30	6.92	$1.70*10^{-4}$	$1.23*10^{-3}$	48.9	31.8	$4.84*10^{-4}$	$9.71*10^{-2}$
OCDD	0.0001	6.85	14.4	$3.50*10^{-4}$	$2.56*10^{-2}$	102.0	66.0	$9.98*10^{-4}$	$2.02*10^{-1}$
2378-TCDF	0.1	2.89	6.07	$3.17*10^{-4}$	$1.08*10^{-2}$	42.8	27.8	$8.97*10^{-4}$	$8.50*10^{-2}$
12378-PCDF	0.05	0.30	0.62	$2.02*10^{-5}$	$1.10*10^{-2}$	4.38	2.85	$5.74*10^{-5}$	$8.70*10^{-3}$
23478-PCDF	0.5	0.54	1.14	$3.31*10^{-5}$	$2.03*10^{-3}$	8.04	5.22	$9.40*10^{-5}$	$1.06*10^{-2}$
123478-HxCDF	0.1	0.87	1.83	$4.80*10^{-5}$	$3.25*10^{-3}$	12.9	8.40	$1.36*10^{-4}$	$2.56*10^{-2}$
123678-HxCDF	0.1	0.83	1.73	$4.54*10^{-5}$	$3.07*10^{-3}$	12.2	7.95	$1.29*10^{-4}$	$2.42*10^{-2}$
123789-HxCDF	0.1	0.56	1.18	$2.94*10^{-5}$	$2.10*10^{-3}$	8.32	5.40	$8.50*10^{-5}$	$1.65*10^{-2}$
234678-HxCDF	0.1	0.33	0.69	$1.74*10^{-5}$	$1.22*10^{-3}$	4.84	3.14	$4.94*10^{-5}$	$9.60*10^{-3}$
1234678-HpCDF	0.01	1.15	2.42	$6.01*10^{-5}$	$4.30*10^{-3}$	17.1	11.1	$1.71*10^{-4}$	$3.39*10^{-2}$
1234789-HpCDF	0.01	0.51	1.06	$2.61*10^{-5}$	$1.88*10^{-3}$	7.48	4.86	$7.41*10^{-5}$	$1.48*10^{-2}$
OCDF	0.0001	2.27	4.77	$1.16*10^{-4}$	$8.47*10^{-3}$	33.7	21.9	$3.31*10^{-4}$	$6.69*10^{-2}$
WHO_{98}-TEQ_{DF}		**1.12**	**2.35**	**$8.12*10^{-5}$**	**$4.17*10^{-3}$**	**17.7**	**11.5**	**$2.30*10^{-4}$**	**$3.29*10^{-2}$**

Table 5-4. WHO_{98}-TEQ_{DF} environmental and exposure media concentrations for the background conditions scenarios, #1 and #2, and the stack emissions demonstration scenarios, #4 and #5.

Description	Background, Scenarios 1 and 2	Emission, Central Scenario 4	Emission, High End Scenario 5
Air, vapor phase, pg/m^3	$2.59*10^{-3}$	$2.45*10^{-5}$	$6.94*10^{-5}$
Air, particle phase, pg/m^3	$1.87*10^{-2}$	$6.04*10^{-5}$	$1.74*10^{-4}$
Soil, untilled, pg/g	1.29	$4.46*10^{-3}$	$3.51*10^{-2}$
Soil, tilled, pg/g	0.65	$4.46*10^{-4}$	$3.51*10^{-3}$
Soil, watershed, pg/g	1.29	$8.91*10^{-4}$	$8.91*10^{-4}$
Surface water, pg/L	$2.63*10^{-3}$	$3.80*10^{-5}$	$3.80*10^{-5}$
Sediment, pg/g	3.37	$2.39*10^{-3}$	$2.39*10^{-3}$
fish lipid, pg/g*	6.33	$5.64*10^{-3}$	$5.64*10^{-3}$
leafy vegetation, pg/g dry	0.45	$1.86*10^{-3}$	$6.39*10^{-3}$
above ground fruit/veg, pg/g fresh	$5.74*10^{-3}$	$1.20*10^{-5}$	$6.37*10^{-5}$
below ground vegetables, pg/g fresh	$1.94*10^{-2}$	$1.63*10^{-5}$	$1.29*10^{-4}$
beef fat, pg/g*	1.58	$4.35*10^{-3}$	$1.65*10^{-2}$
milk fat, pg/g*	1.10	$3.05*10^{-3}$	$1.11*10^{-3}$
chicken fat, pg/g*	0.61	$2.02*10^{-3}$	$1.38*10^{-2}$
egg fat, pg/g*	0.71	$2.25*10^{-3}$	$1.55*10^{-2}$

* These food concentrations were not uniformly required for all scenarios. For example, the central scenarios did include a fish ingestion pathway, but the high scenarios did not. Similarly, chicken, milk, and egg pathways are demonstrated outside the context of a scenario. These concentrations are presented here for completeness.

Table 5-5. Environmental and exposure media concentrations for 2,3,7,8-TCDD ("dioxin"), 2,3,4,7,8-PCDF ("furan") and 2,3,3',4,4',5,5'-HPCB (PCB) for the soil contamination demonstration, scenario #3, and the effluent discharge demonstration, scenario #6 (NA = not applicable).

Description	Scenario 3 - Soil Contamination			Scenario 6 - Effluent Discharge		
	dioxin	furan	PCB	dioxin	furan	PCB
Air, vapor phase, pg/m^3	0.004	0.007	0.002	NA	NA	NA
Air, particle phase, pg/m^3	0.0002	0.0002	0.0002	NA	NA	NA
Soil, untilled, pg/g	357	357	357	NA	NA	NA
Soil, tilled, pg/g	61	61	61	NA	NA	NA
Sediment, pg/g*	1.44	0.53	1.56	4.91	3.84	6.40
Surface water, pg/L	0.012	0.091	0.0016	0.018	0.029	0.0029
fish lipid, pg/g**	4.3	2.6	108.9	6.4	8.0	195.7
leafy vegetation, pg/g dry	0.23	0.60	0.26	NA	NA	NA
above ground fruit/veg, pg/g fresh	0.0006	0.0011	0.0006	NA	NA	NA
below ground vegetables, pg/g fresh	2.0	23.4	1.30	NA	NA	NA
beef fat, pg/g**	54.4	40.1	21.8	NA	NA	NA
milk fat, pg/g**	27.5	20.4	11.0	NA	NA	NA
chicken fat, pg/g**	204.1	171.8	171.7	NA	NA	NA
egg fat, pg/g**	180.9	181.1	.150.8	NA	NA	NA

* The sediment concentration given for Scenario 3 is the bottom sediment, while the concentration for Scenario 6 is the suspended sediment. These are the concentrations used in the prediction of fish tissue concentrations.

** These food concentrations were not uniformly required for all scenarios. For example, the central scenarios did include a fish ingestion pathway, but the high scenarios did not. Similarly, chicken, milk, and egg pathways are demonstrated outside the context of a scenario. These concentrations are presented here for completeness

Table 5-6. Individual congener and Toxic Equivalent (WHO_{98}-TEQ_{DF}) concentrations for predicted beef concentration for the background high scenario, scenario # 2, and the stack emission high scenario, scenario 5.

Congeners	TEF	Scenario 2: Background high, pg/g lipid	Scenario 5: Stack emission high, pg/g lipid
2378-TCDD	1.0	0.25	0.021
12378-PCDD	1.0	0.74	0.005
123478-HxCDD	0.1	0.37	0.002
123678-HxCDD	0.1	0.40	0.003
123789-HxCDD	0.1	0.75	0.004
1234678-HpCDD	0.01	1.59	0.004
OCDD	0.0001	9.08	0.011
2378-TCDF	0.1	0.08	0.023
12378-PCDF	0.05	0.13	0.001
23478-PCDF	0.5	0.50	0.008
123478-HxCDF	0.1	0.57	0.008
123678-HxCDF	0.1	0.56	0.007
123789-HxCDF	0.1	0.09	0.004
234678-HxCDF	0.1	0.27	0.002
1234678-HpCDF	0.01	0.71	0.002
1234789-HpCDF	0.01	0.24	0.002
OCDF	0.0001	0.25	0.001
WHO_{98}-TEQ_{DF}		**1.58**	**0.017**

Table 5-7. Lifetime average daily doses, LADD, of Toxic Equivalents (TEQs), for the background scenarios, #1 and #2, and for the stack emission scenarios, #4 and #5.

Scenario/Pathway	LADD, ng/kg-day	Percent of total scenario exposure
Scenario 1 - Background Central		
Soil Ingestion	$5.42*10^{-7}$	6
Soil Dermal Contact	$3.23*10^{-9}$	<1
Inhalation	$4.57*10^{-7}$	5
Water Ingestion	$8.70*10^{-8}$	1
Fish Ingestion	$6.51*10^{-6}$	78
Vegetable Ingestion	$6.95*10^{-7}$	8
Fruit Ingestion	$1.09*10^{-7}$	1
Total	$8.40*10^{-6}$	100
Scenario 2 - Background High		
Soil Ingestion	$3.25*10^{-6}$	4
Soil Dermal Contact	$4.40*10^{-8}$	<1
Inhalation	$2.34*10^{-6}$	3
Water Ingestion	$2.90*10^{-8}$	<1
Beef Ingestion	$8.30*10^{-5}$	91
Vegetable Ingestion	$2.32*10^{-6}$	2
Fruit Ingestion	$3.65*10^{-7}$	<1
Total	$9.16*10^{-5}$	100

Table 5-7. (Cont'd)

Scenario/Pathway	LADD, ng/kg-day	Percent of total scenario exposure
Scenario 4 - Stack Emission Central		
Soil Ingestion	$1.87*10^{-9}$	18
Soil Dermal Contact	$3.22*10^{-12}$	<1
Inhalation	$1.43*10^{-9}$	14
Water Ingestion	$6.85*10^{-11}$	1
Fish Ingestion	$5.81*10^{-9}$	57
Vegetable Ingestion	$8.28*10^{-10}$	8
Fruit Ingestion	$2.29*10^{-10}$	2
Total	$1.02*10^{-8}$	100
Scenario 5 - Stack Emission High		
Soil Ingestion	$8.86*10^{-8}$	9
Soil dermal contact	$2.55*10^{-10}$	<1
Inhalation	$2.68*10^{-8}$	2
Water ingestion	$4.19*10^{-10}$	<1
Beef ingestion	$8.65*10^{-7}$	86
Vegetable ingestion	$1.83*10^{-8}$	3
Fruit ingestion	$4.05*10^{-9}$	<1
Total	$1.00*10^{-6}$	100

Table 5-8. Lifetime average daily doses, LADD, for 2,3,7,8-TCDD ("dioxin"), 2,3,4,7,8-PCDF ("furan") and 2,3,3',4,4',5,5'-HPCB (PCB) for the soil contamination demonstration, scenario #3, and the effluent discharge demonstration, scenario #6.

Scenario/Pathway	Dioxin, ng/kg-day	Furan, ng/kg-day	PCB, ng/kg-day	Percent of total scenario exposure*
Scenario 3 - Soil Contamination				
Soil Ingestion	$8.99*10^{-4}$	$8.99*10^{-4}$	$8.99*10^{-4}$	23
Soil dermal contact	$4.20*10^{-6}$	$4.20*10^{-6}$	$4.20*10^{-6}$	<1
Inhalation	$4.75*10^{-7}$	$8.12*10^{-7}$	$2.40*10^{-7}$	<1
Water ingestion	$1.33*10^{-7}$	$1.00*10^{-6}$	$1.81*10^{-8}$	<1
Beef ingestion	$2.85*10^{-3}$	$2.10*10^{-3}$	$1.14*10^{-3}$	73
Vegetable ingestion	$1.71*10^{-4}$	$2.05*10^{-3}$	$1.08*10^{-4}$	4
Fruit ingestion	$3.75*10^{-8}$	$7.25*10^{-8}$	$4.04*10^{-8}$	<1
Total	$4.06*10^{-3}$	$5.19*10^{-3}$	$2.29*10^{-3}$	100
Scenario 6 - Effluent Discharge				
Water ingestion	$3.22*10^{-8}$	$5.15*10^{-8}$	$5.29*10^{-9}$	<1
Fish ingestion	$6.60*10^{-6}$	$8.26*10^{-6}$	$2.01*10^{-4}$	100
Total	$6.63*10^{-6}$	$8.31*10^{-6}$	$5.01*10^{-5}$	100

* Results in this column are for dioxin

Table 5-9. Lifetime Average Daily Doses, LADD, of Toxic Equivalents (WHO_{98}-TEQ_{DF}) for exposure pathways evaluated outside of the scenarios for background conditions and stack emissions.

Setting/Exposure Pathway	WHO_{98}-TEQ_{DF} LADD, ng/kg-day
Background Conditions, high end setting	
Milk ingestion	$4.09*10^{-5}$
Chicken ingestion	$2.64*10^{-6}$
Egg ingestion	$3.79*10^{-6}$
Fish ingestion, high ingestion rate	$6.78*10^{-5}$
Stack emissions, high end setting	
Milk ingestion	$4.12*10^{-7}$
Chicken ingestion	$5.92*10^{-8}$
Egg ingestion	$8.31*10^{-8}$
Fish ingestion, high ingestion rate	$6.05*10^{-8}$

Table 5-10. Lifetime Average Daily Doses, LADD, of 2,3,7,8-TCDD ("dioxin"), 2,3,4,7,8-PCDF ("furan") and 2,3,3',4,4',5,5'-HPCB ("PCB") for exposure pathways evaluated outside of the scenarios for the soil contamination and the effluent discharge settings.

Setting/Pathway	Dioxin, ng/kg-day	Furan, ng/kg-day	PCB, ng/kg-day
Soil Contamination			
Milk ingestion	$1.19*10^{-3}$	$8.89*10^{-4}$	$4.77*10^{-4}$
Chicken ingestion	$8.79*10^{-4}$	$7.48*10^{-4}$	$7.39*10^{-4}$
Egg ingestion	$1.09*10^{-3}$	$1.09*10^{-3}$	$9.09*10^{-4}$
Fish ingestion, high ingestion rate	$4.62*10^{-5}$	$2.74*10^{-5}$	$1.17*10^{-3}$
Scenario 6 - Effluent Discharge			
Fish ingestion, high ingestion rate	$2.06*10^{-5}$	$3.44*10^{-5}$	$6.28*10^{-4}$

Table 5-11. Relative magnitude of all exposure pathways evaluated for the background setting and the stack emission, high exposure scenario setting (see table bottom for notes).

Exposure Pathway	Background conditions	Stack emissions	Soil Contamination
Beef Ingestion	1.00	1.00	1.00
Milk Ingestion	0.49	0.48	0.42
Fish Ingestion	0.82	0.07	0.02
Egg Ingestion	0.05	0.10	0.38
Soil Ingestion	0.04	0.10	0.31
Chicken Ingestion	0.03	0.07	0.31
Inhalation	0.02	0.03	<0.01
Vegetable Ingestion	0.02	0.02	0.06
Soil Dermal - high end	<0.01	<0.01	<0.01
Fruit Ingestion	<0.01	<0.01	<0.01
Water ingestion	<0.01	<0.01	<0.01

Notes:
1. 1.00 is the highest pathway, and the values less than 1.00 describe the relation of that pathway to the highest pathway.
2. This table is for the high exposure farm setting only. For the stack emission scenario, the farm was located 500 meters from the stack. Also, the fish ingestion pathway was for the high ingestion rate, 25 g/day, and the soil pathways - dermal and soil ingestion - were for the high contact assumptions only.
3. For the background and stack emission scenarios, results are for TEQs; for the soil contamination scenario, results are for 2,3,7,8-TCDD.

Table 5-12. Cancer risk estimates for the background and stack emission high end scenarios.

Setting/Exposure Pathway	Cancer Risk
Background Conditions, high end setting	
Soil Ingestion	$1.22*10^{-6}$
Soil Dermal Contact	$5.27*10^{-8}$
Inhalation	$2.34*10^{-6}$
Water Ingestion	$2.90*10^{-7}$
Beef Ingestion	$8.30*10^{-5}$
Vegetable Ingestion	$2.36*10^{-6}$
Fruit Ingestion	$3.65*10^{-7}$
Total	$8.96*10^{-5}$
Stack emissions, high end setting	
Soil Ingestion	$3.32*10^{-8}$
Soil Dermal Contact	$3.19*10^{-10}$
Inhalation	$2.68*10^{-8}$
Water Ingestion	$4.19*10^{-10}$
Beef Ingestion	$8.65*10^{-7}$
Vegetable Ingestion	$1.83*10^{-8}$
Fruit Ingestion	$4.05*10^{-9}$
Total	$9.48*10^{-7}$