1. INTRODUCTION

1.1. BACKGROUND

In May of 1991, the United States Environmental Protection Agency (EPA) announced a scientific reassessment of the human health and exposure issues concerning dioxin and dioxin-like compounds (56 FR 50903). This reassessment resulted in two reports: a health reassessment document (U.S. EPA, 1994), and an exposure document entitled *Estimating Exposure to Dioxin-Like Compounds*, which expanded upon a 1988 draft exposure report entitled, *Estimating Exposure to 2,3,7,8-TCDD* (U.S. EPA, 1988). The document *Estimating Exposure to Dioxin-Like Compounds* has now been expanded to four volumes, as discussed below. This document can be used with the health reassessment document to evaluate potential health risks from exposure to dioxin-like compounds.

Numerous public comments were received on the draft documents and they were reviewed by EPA's Science Advisory Board (SAB) in 1995 (U.S. EPA, 1995). In a related document, EPA also described the data and methods for evaluating risks to aquatic life from 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) (U.S. EPA, 1993). In 1997, EPA released a workshop review version of Chapter 8 of the Health Reassessment documents, the chapter on dose-response modeling (U.S. EPA, 1997). In 1998, EPA released a workshop review version of the sources inventory (U.S. EPA, 1998), one of the four volumes of the current Exposure Reassessment Document. This current version of the exposure document incorporates changes as a result of comments received on earlier versions of the documents, the SAB review in 1995, the workshop held in 1998 on the sources inventory, and a wealth of new information on dioxins available in the open literature.

The purpose of the exposure portion of the dioxin reassessment is threefold: 1) to inventory the known sources of release of dioxins into the environment, 2) to develop an understanding of dioxins in the environment, including fate and transport properties, environmental and exposure media concentrations, background and potentially elevated exposures, and temporal trends in exposure, and 3) provide site-specific procedures for evaluating the incremental exposures due to specific sources of dioxin-like compounds. The exposure document is presented in four volumes. Following is a summary of the material contained in each of these volumes:

Volume I - Executive Summary

This volume includes summaries of findings from Volumes II, III, and IV. It also includes a unique section on research needs and recommendations for dioxin-like compounds.

Volume II - Inventory of Sources of Dioxin in the United States

This volume presents the inventory of known sources of dioxin release into the U.S. environment. This inventory is presented for two time frames, represented by the years 1987 and 1995. Ongoing releases into air, water, and soil are quantified where possible. Also, estimates of release from "reservoir" sources of dioxins, such as soils or pentachlorophenol-treated utility poles, are presented.

Volume III - Properties, Environmental Levels, and Background Exposures

This volume presents and evaluates information on the physical-chemical properties, environmental fate, environmental and exposure media levels, background and potentially elevated human exposures, and temporal trends of dioxin-like compounds in the U.S. environment during the 20th century. It summarizes and evaluates relevant information obtained from published literature searches, EPA program offices and other Federal agencies, and published literature. From these data sources, exposure media concentrations, and average as well as potentially elevated exposure levels for the U.S. population are quantified. The data contained in this volume are expected to be current through 1998 with some new information published during 1999.

Volume IV - Site-Specific Assessment Procedures

This volume presents procedures for evaluating the incremental impact from sources of dioxin release into the environment. The sources covered include contaminated soils, stack emissions, and point discharges into surface water. This volume includes sections on: exposure parameters and exposure scenario development; stack emissions and atmospheric transport modeling; aquatic and terrestrial fate, and food chain modeling; demonstration of methodologies; and uncertainty evaluations including exercises on sensitivity analysis and model validation, review of Monte Carlo assessments conducted for dioxin-like compounds, and other discussions. The data contained in this volume are current through 1998 with some new information published during 1999.

1.2. DESCRIPTION OF DIOXIN-LIKE COMPOUNDS

This document addresses compounds in the following chemical classes: polychlorinated dibenzo-p-dioxins (PCDDs or CDDs), polychlorinated dibenzofurans (PCDFs or CDFs), and polychlorinated biphenyls (PCBs). The CDDs include 75 individual compounds, and CDFs include 135 different compounds. These individual compounds are technically referred to as congeners. Only 7 of the 75 congeners of CDDs are thought to have dioxin-like toxicity; these are ones with chlorine substitutions in, at least, the 2, 3, 7, and 8 positions. Only 10 of the 135 possible congeners of CDFs are thought to have

dioxin-like toxicity; these also are ones with substitutions in, at least, the 2, 3, 7, and 8 positions. There are 209 PCB congeners. Only 13 of the 209 congeners are thought to have dioxin-like toxicity; these are PCBs with four or more chlorines with just one or no substitution in the ortho position. These compounds are sometimes referred to as coplanar, meaning that they can assume a flat configuration with rings in the same plane. Similarly configured polybrominated biphenyls are likely to have similar properties; however, the data base on these compounds, with regard to dioxin-like activity, has been less extensively evaluated.

The physical/chemical properties of each congener vary according to the degree and position of chlorine substitution. The chlorinated dibenzodioxins and dibenzofurans are tricyclic aromatic compounds with similar physical and chemical properties, and both classes are similar structurally. Certain PCBs (the so-called coplanar or mono-ortho coplanar congeners) are also structurally and conformationally similar. The most widely studied of these compounds is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). This compound, often called simply dioxin, represents the reference compound for this class of compounds. The structure of 2,3,7,8-TCDD and several related compounds is shown in Figure 1-1.

1.3. TOXICITY EQUIVALENCY FACTORS

The dioxin-like compounds are often found in complex mixtures. For risk assessment purposes, a toxicity equivalency procedure was developed to describe the cumulative toxicity of these mixtures. This procedure involves assigning individual toxicity equivalency factors (TEFs) to the 2,3,7,8 substituted CDD and CDF congeners (the sum of these two abbreviated CDD/CDF in this document) and to selected coplanar and mono-ortho PCBs (the sum of the three groups often abbreviated CDD/CDF/PCB). TEFs are estimates of the toxicity of dioxin-like compounds relative to the toxicity of 2,3,7,8-TCDD, which is assigned a TEF of 1.0. Calculating the toxic equivalency (TEQ) of a mixture involves multiplying the concentration of individual congeners by their respective TEF. The sum of the TEQ concentrations for the individual congeners is the TEQ concentration for the mixture. This is described mathematically as follows:

$$TEQ \cong \Sigma_{i-n}\left(Congener_i \times TEF_i\right) + \left(Congener_j \times TEF_j\right) + \ldots\ldots\left(Congener_n \times TEF_n\right)$$

On the most basic level, TEFs compare the potential toxicity of each dioxin-like compound comprising the mixture to the well-studied and understood toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), the most toxic member of the group. To

assign TEF values, scientist have reviewed the toxicological databases along with considerations of chemical structure, persistence, and resistance to metabolism. Since 1989, three different TEF schemes have been developed and used for evaluating the TEQ of mixtures of CDDs, CDFs and dioxin-like PCBs. A problem arises in that past and present quantitative exposure and risk assessments may not have clearly identified which of three TEF schemes were used to estimate the TEQ. This Dioxin Exposure Reassessment document adopted a uniform TEQ nomenclature that clearly distinguishes between the three major TEF schemes. The following presents a taxonomy of TEQ.

1.3.1. I-TEQ_{DF}

Described by EPA in 1989 (U.S. EPA, 1989), the I-TEQ_{DF} procedure assigns TEFs only for the 7 dioxin (CDDs) and 10 furans (CDFs). The TEF values for the I-TEQ_{DF} are shown in Table 1-1. Note that the scheme does not include dioxin-like PCBs. The nomenclature for this scheme is I-TEQ_{DF}, where 'I' represents 'International', TEQ represents the 2,3,7,8-TCDD Toxic Equivalence of the mixture, and the subscript DF indicates that only dioxins (Ds) and furans (Fs) are included in the TEF scheme. In this document, this is sometimes shortened to I-TEQ without the subscripts where it is understood, in the context of the discussion, that the TEQ mixture refers to both dioxins and furans. There may also be occasion where I-TEQ_D or I-TEQ_F are used, when it is only desired to denote the TEQ concentrations of dioxins only or furans only in the mixture.

1.3.2. TEQ_{DFP}-WHO_{94}

In 1994, the World Health Organization (WHO) added 13 dioxin-like PCBs to the TEF scheme for dioxins and furans (Ahlborg et al., 1994). However, no changes were made to the TEFs for dioxins and furans. The nomenclature for this TEF scheme is TEQ_{DFP}-WHO_{94}, where TEQ represents the 2,3,7,8-TCDD Toxic Equivalence of the mixture, and the subscript DFP indicates that dioxins (Ds) furans (Fs) and dioxin-like PCBs (P) are included in the TEF scheme. The subscript 94 following WHO displays the year changes were made to the TEF scheme. As in the above scheme, there are occasions where the DFP subscript has been tailored to the context of the discussion. For example, to describe the TEQ concentration of only the dioxin-like PCBs of a mixture using this WHO 1994 scheme, the nomenclature reads, TEQ_P-WHO_{94}. For a mixture containing dioxins, furans, and coplanar PCBs, the full TEQ_{DFP}-WHO_{94} is used. There are occasions when TEQ_{DF}-WHO_{94} is used, since the TEFs for CDD/CDFs did not change in the 1994 WHO designations - TEQ concentrations using the international TEFs for CDD/CDFs would be described, as noted above, as I-TEQ. Table 1-2 displays the TEFs for the dioxin-like coplanar PCBs, developed in 1994 by the World Health Organization.

1.3.3. TEQ_{DFP}-WHO_{98}

In 1998, the WHO re-evaluated the previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg, et al., 1998). Changes were made to the 1989 International TEFs for dioxins and furans, as well as to the 1994 TEFs for coplanar PCBs. The nomenclature for this TEF scheme is TEQ_{DFP}-WHO_{98}, where TEQ represents the 2,3,7,8-TCDD Toxic Equivalence of the mixture, and the subscript DFP indicates that dioxins (Ds) furans (Fs) and dioxin-like PCBs (P) are included in the TEF scheme. The subscript 98 following WHO displays the year changes were made to the TEF scheme. As noted previously, the subscripts D, F, and P are used in various combinations to denote TEQ concentrations for mixtures including only CDD/CDFs (TEQ_{DF}-WHO_{98}), only PCBs (TEQ_{P}-WHO_{98}), or all three (TEQ_{DFP}-WHO_{98}). Table 1-3 displays the TEF scheme for the TEQ_{DFP}-WHO_{98}. Note that the changes to the TEFs for CDD/CDFs are as follows:

- For 1,2,3,7,8-PeCDD, the new WHO TEF is 1 and the I-TEF was 0.5;
- For OCDD, the new WHO TEF is 0.0001 and the I-TEF was 0.001; and
- For OCDF, the new WHO TEF is 0.0001 and the I-TEF was 0.001.

Note that the changes to the TEFs for dioxin-like PCBs (Ps) are as follows:

- For PCB 77, the new TEF is 0.0001;
- The addition of PCB 81 (i.e., 3,4,4',5-TCB); and
- For the two di-ortho substituted HpCBs in the 1994 TEF scheme (i.e., PCBs 170 and 180), TEFs of zero have been assigned in the new WHO TEF scheme.

1.4. CONTENTS OF THIS VOLUME

The purpose of this volume is to: (1) summarize information on the physical and chemical properties of dioxin-like compounds; (2) provide an overview of the levels of dioxin-like compounds found in environmental media and food; (3) estimate background exposures to dioxin-like compounds for the general population of the United States; (4) provide information on the potential for elevated exposures among certain subpopulations of the United States; and (5) summarize the evidence that suggests a downward trend in dioxin-like concentrations in the environment, as well as trends in exposure. These topics are organized in this volume as follows:

Chapter 2 - Physical and Chemical Properties and Fate

This chapter summarizes available information regarding the physical and chemical properties and fate of the dioxin-like compounds. Physical/ chemical properties

addressed in Chapter 2 include melting point, water solubility, vapor pressure, Henry's Law constant, octanol/water partition coefficient, organic carbon partition coefficient, and photochemical quantum yield. Fate and transport processes addressed include photolysis, oxidation, hydrolysis, biodegradation, volatilization, and sorption. Biologically-mediated transport properties (i.e., bioconcentration, plant uptake, etc.) are also addressed in this volume. (These properties are also addressed in Volume IV: Site-Specific Assessment Procedures.) These data were compiled from a review of the current scientific literature on dioxin-like compounds.

Chapter 3 - Levels of CDD, CDF, and PCB Congeners

This chapter provides an overview of the concentrations at which dioxin-like compounds have been found in the environment and food based on data presented in the recent published literature. Data are presented for air, soil, sediment, water, and foods. For foods, the general focus is on foods with relatively high fat content (i.e., beef, pork, poultry and eggs, milk and dairy products, fish, and vegetable fats) because these items are most likely to contain dioxins and related compounds. Data from Government-sponsored monitoring studies and studies reported in the peer-reviewed literature are used in this chapter to estimate U.S. background concentrations of dioxin-like compounds in the various environmental media and foods. In order to represent current exposure concentrations, data used for the calculation of background media levels are based on studies published in the late 1980s and 1990s, but primarily in the 1990s. The studies used for the estimation of background concentrations were also chosen on the basis of credibility and representativeness. CDD/CDF profiles for environmental media are also presented in this chapter.

Chapter 4 - Human Exposures to CDD/CDF, and PCB Congeners

This chapter assesses background exposures to the dioxin-like compounds among the general population of the United States. Recent assessments of background exposures cited in the scientific literature are summarized, and background exposure estimates, based on the data presented in Chapter 3, are presented. Data on the concentrations of dioxin-like compounds in human tissue (i.e., adipose tissue, blood, and human breast milk) are also presented. Two methods are used in to estimate background daily intake of dioxin-like compounds. One method estimates background exposures based on pharmacokinetic modeling using the human tissue data. The other derives background exposure estimates from dietary intake and

contact with other media containing dioxin-like compounds. The primary focus of this chapter is background exposure among the general population.

Chapter 5 - Potentially Elevated Populations

This chapter focuses on elevated exposures that may occur among the general population from dietary habits such as breast feeding or high rates of fish ingestion, increased environmental levels of dioxin-like compounds from localized sources, or cigarette smoking. This chapter does not, however, address occupational or accidental exposure. Epidemiological studies that have evaluated whether elevated dioxin exposure has occurred to certain workers in the chemical industry, members of the Air Force who worked with Agent Orange, and residents of Seveso, Italy, who were exposed as a result of a pesticide plant explosion are fully discussed in the Epidemiology Chapter of the Dioxin Health Reassessment Document.

Chapter 6 - Temporal Trends

This chapter describes trends in the levels of dioxin-like compounds that have been observed in various environmental media and foods, as well as evidence of downward trends in exposure to dioxin-like compounds in humans. The downward trend in human exposure is supported by a modeling exercise that reconstructs the most likely past doses of dioxin-like compounds contributing to observed body burdens. Reviews of several studies and the modeling exercise are followed by several key observations with regard to temporal trends of dioxin-like compounds.

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Table 1-1. The TEF Scheme for I-TEQ_{DF}

Dioxin (D) Congener	TEF	Furan (F) Congener	TEF
2,3,7,8-TCDD	1.0	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	0.5	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	

Table 1-2. The TEF Scheme for dioxin-like coplanar PCBs, as determined by the World Health Organization in 1994

Chemical Structure	IUPAC Number	TEF
3,3',4,4'-TeCB	PCB-77	0.0005
2,3,3',4,4'-PeCB	PCB-105	0.0001
2,3,4,4',5-PeCB	PCB-114	0.0005
2,3',4,4',5-PeCB	PCB-118	0.0001
2',3,4,4',5-PeCB	PCB-123	0.0001
3,3',4,4',5-PeCB	PCB-126	0.1
2,3,3',4,4',5-HxCB	PCB-156	0.0005
2,3,3',4,4',5'-HxCB	PCB-157	0.0005
2,3',4,4',5,5'-HxCB	PCB-167	0.00001
3,3',4,4',5,5'-HxCB	PCB-169	0.01
2,2',3,3',4,4',5-HpCB	PCB-170	0.0001
2,2',3,4,4',5,5'-HpCB	PCB-180	0.00001
2,3,3',4,4',5,5'-HpCB	PCB-189	0.0001

Table 1-3. The TEF Scheme for TEQ_{DFP}-WHO_{98}

Dioxin Congeners	TEF	Furan Congeners	TEF
2,3,7,8-TCDD	1.0	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	1.0	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.0001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	0.0001

Chemical Structure	IUPAC Number	TEF
3,3',4,4'-TeCB	PCB-77	0.0001
3,4,4',5-TCB	PCB-81	0.0001
2,3,3',4,4'-PeCB	PCB-105	0.0001
2,3,4,4',5-PeCB	PCB-114	0.0005
2,3',4,4',5-PeCB	PCB-118	0.0001
2',3,4,4',5-PeCB	PCB-123	0.0001
3,3',4,4',5-PeCB	PCB-126	0.1
2,3,3',4,4',5-HxCB	PCB-156	0.0005
2,3,3',4,4',5'-HxCB	PCB-157	0.0005
2,3',4,4',5,5'-HxCB	PCB-167	0.00001
3,3',4,4',5,5'-HxCB	PCB-169	0.01
2,3,3',4,4',5,5'-HpCB	PCB-189	0.0001

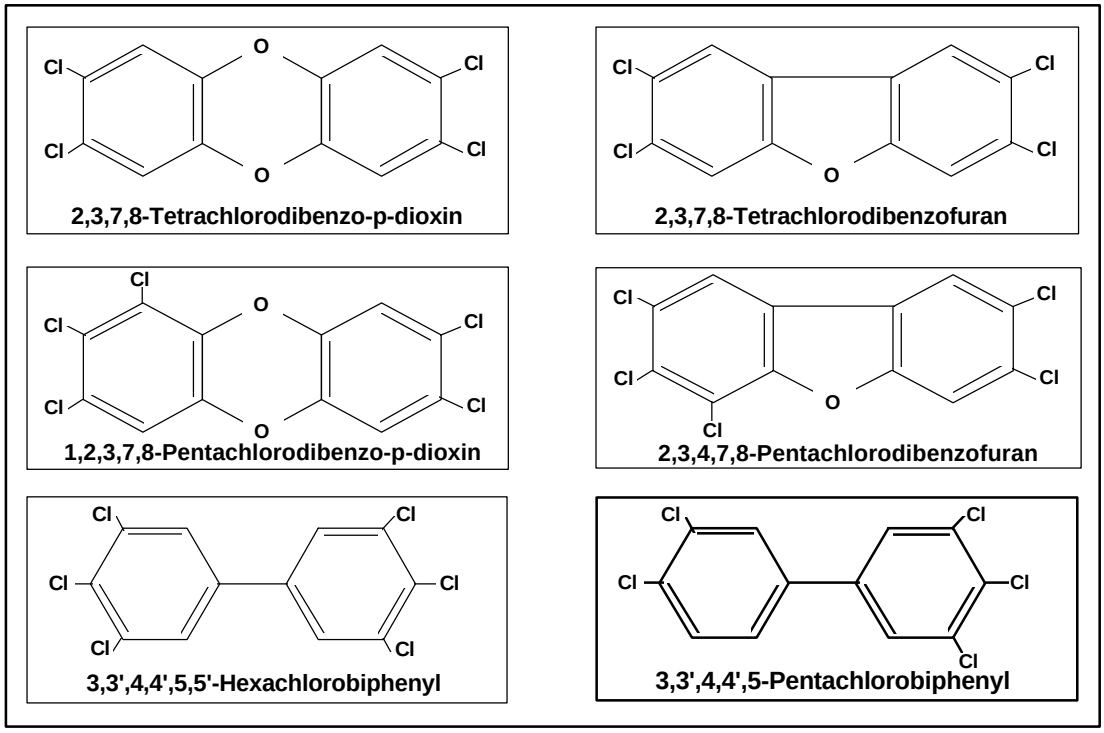

Figure 1-1. Chemical Structure of 2,3,7,8-TCDD and Related Compounds