United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/6-88/005Cb
June 1994
External Review Draft

EPA

Estimating Exposure to Dioxin-Like Compounds

Review Draft (Do Not Cite or Quote)

Volume II: Properties, Sources, Occurrence and Background Exposures

Notice

This document is a preliminary draft. It has not been formally released by EPA and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

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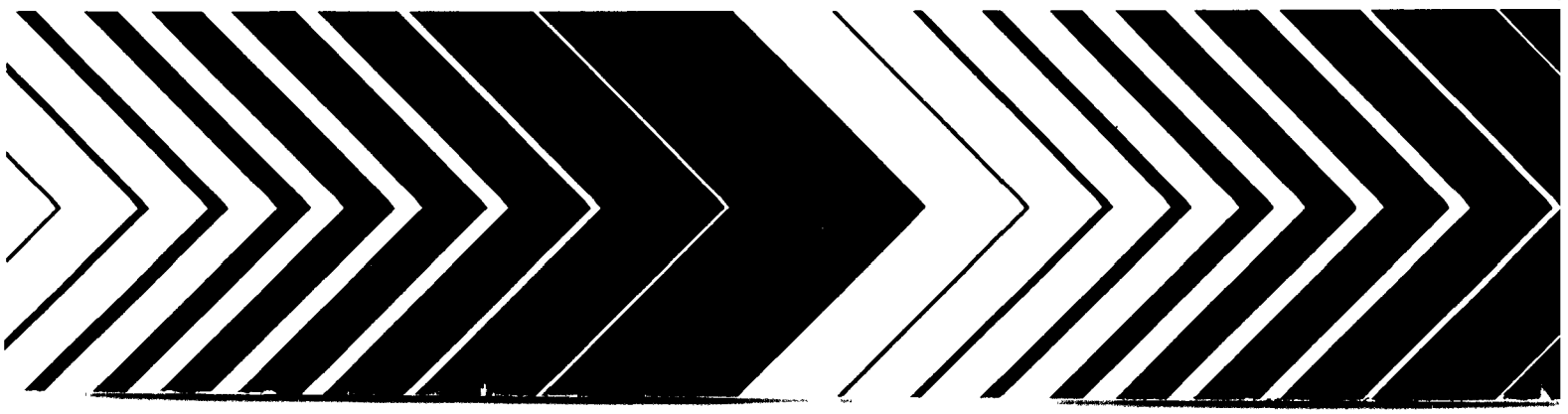

Next Stages in the Reassessment Process

As described previously, public briefings will be held during the first week of the public comment period to be followed by formal public hearings in December 1994. After the close of the public comment period, the Agency's Science Advisory Board (SAB) will review the draft documents in public session (early 1995). Following SAB review, the draft documents will be revised, comments and revisions will be incorporated, and final documents will be issued.

8/30/94
Date

Acting Carl R. Gerber
Assistant Administrator
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Billing Code: 6560-50-P

ecosystems from exposure to dioxins. Research efforts are focused on the study of organisms in aquatic food webs to identify the effects of dioxin exposure that are likely to result in significant population impacts. A report titled, *Interim Report on Data and Methods for the Assessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) Risks to Aquatic Organisms and Associated Wildlife* (EPA/600/R-93/055), was published in April 1993. This report will serve as a background document for assessing dioxin-related ecological risks. Ultimately, these data will support the development of aquatic life criteria which will aid in the implementation of the Clean Water Act.

As mentioned previously, completion of the health assessment and exposure documents involves three phases: Phase 1 involved drafting state-of-the-science chapters and a dose-response model for the health assessment document, expanding the exposure document to address dioxin related compounds, and conducting peer-review workshops by panels of experts. This phase has been completed.

Phase 2, preparation of the risk characterization, began during the September 1992 workshops with discussions by the peer-review panels and formulation of points to be carried forward into the risk characterization. Following the September 1993 workshop, this work was completed and was incorporated as Chapter 9 (Volume III) of the draft health assessment document. This phase has been completed.

Phase 3 is currently underway. It includes making External Review Drafts of both the health assessment document and the exposure document available for public review and comment.

scientific experts from outside the Agency reviewed the draft documents and provided valuable comments. It also should be noted that outside scientists have been heavily involved throughout the developmental process of writing and reviewing these draft documents. With this notice, the External Review Drafts of both draft documents are being released for a 120-day public review and comment period.

Current Stage of the Scientific Reassessment of Dioxin

The scientific reassessment of dioxin consists of five activities:

1. Update and revision of the health assessment document for dioxin.
2. Laboratory research in support of the dose-response model.
3. Development of a biologically based dose-response model for dioxin.
4. Update and revision of the dioxin exposure assessment document.
5. Research to characterize ecological risks in aquatic ecosystems.

The first four activities have resulted in two draft documents (the health assessment document and exposure document) for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and related compounds. These companion documents, which form the basis for the Agency's reassessment of dioxin, have been used in the development of the risk characterization chapter that follows the health assessment (Chapter 9, Volume III). The process for developing these documents consisted of three phases which are outlined in later paragraphs.

The fifth activity, which is in progress at EPA's Environmental Research Laboratory in Duluth, Minnesota, involves characterizing ecological risks in aquatic

to hear and receive public comments and reviews of the proposed plans, and to receive any current, scientifically relevant information.

In the Fall of 1992, the Agency convened two peer-review workshops to review draft documents related to EPA's scientific reassessment of the health effects of dioxin. The first workshop was held September 10 and 11, 1992, to review a draft exposure assessment titled, *Estimating Exposures to Dioxin-Like Compounds*. The second workshop was held September 22-25, 1992, to review eight chapters of a future draft *Health Assessment Document for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds*. Peer-reviewers were also asked to identify issues to be incorporated into the risk characterization, which was under development.

In the Fall of 1993, a third peer-review workshop was held on September 7 and 8, to review a draft of the revised and expanded Epidemiology and Human Data Chapter, which also would be part of the future health assessment document. The revised chapter provided an evaluation of the scientific quality and strength of the epidemiology data in the evaluation of toxic health effects, both cancer and noncancer, from exposure to dioxin, with an emphasis on the specific congener, 2,3,7,8-TCDD.

Prior to each workshop, the draft documents or chapters were made available in keeping with the Agency's continuing commitment to conduct the reassessment of dioxin in an open and participatory manner, to keep the public informed of its progress, and to encourage public participation in the document development process. The public also was invited to attend the workshops, to present oral comments, and/or to submit written comments. At each workshop, a panel of

adverse health effects of dioxin in people, of the pathways to human exposure, and of the toxic effects of dioxin to the environment. The reassessment is part of the Agency's goals to improve the research and science base and to incorporate improved research and science into EPA decisions.

History

In 1985 and 1988, the Agency prepared assessments of the human health risks from environmental exposures to dioxin. Also, in 1988, a draft exposure document was prepared that presented procedures for conducting site-specific exposure assessments to dioxin-like compounds. These assessments were reviewed by the Agency's Science Advisory Board (SAB). At the time of the 1988 assessments, there was general agreement within the scientific community that there could be a substantial improvement over the existing approach to analyzing dose response, but there was no consensus as to a more biologically defensible methodology. The Agency was asked to explore the development of such a method. The Agency's reassessment activities are in response to this request.

Stages in the Reassessment Process That Have Been Completed

The EPA had endeavored to make each phase of the reassessment of dioxin an open and participatory effort. On November 15, 1991, and April 28, 1992, public meetings were held to discuss the Agency's plans and activities for the reassessment,

For the exposure assessment document, send comments to: Dioxin Exposure Assessment Comments, Technical Information Staff (8601), Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460.

FOR FURTHER INFORMATION, CONTACT:

For questions on the overall reassessment of dioxin or technical questions on the health assessment document: William Farland, Office of Health and Environmental Assessment (8601), Office of Research and Development, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460; telephone (202) 260-7315; fax (202) 260-0393.

For technical questions on the exposure assessment: John Schaum, Exposure Assessment Group (8603), Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460; telephone (202) 260-8909; fax (202) 260-1722.

SUPPLEMENTARY INFORMATION:

The Scientific Reassessment of Dioxin

In April 1991, EPA announced that it would conduct a scientific reassessment of the health risks of exposure to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and chemically similar compounds collectively known as dioxin. The EPA has undertaken this task in response to emerging scientific knowledge of the biological, human health, and environmental effects of dioxin. Significant advances have occurred in the scientific understanding of mechanisms of dioxin toxicity, of the carcinogenic and other

Agency, 26 W. Martin Luther King Drive, Cincinnati, OH 45268; telephone (513) 569-7562; fax (513) 569-7566. Please provide your name, mailing address, document title, and EPA number.

Please note that the two summary volumes also will be made available as WordPerfect 5.1 files on 3½" PC-DOS formatted disks. Please request by document title and EPA number:

Risk Characterization Chapter (Vol. III-Health), EPA/600/BP-92/001ca (disk)

Executive Summary Chapter (Vol. I-Exposure), EPA/600/6-88/005Caa (disk)

The draft documents will be provided for inspection at the ORD Public Information Shelf, EPA Headquarters Library, 401 M Street, S.W., Washington, DC 20460, between the hours of 10:00 a.m. and 2:00 p.m., Monday through Friday, except for Federal holidays, and at all of the EPA Regional and Laboratory libraries.

Submitting Comments

All comments must be in writing. Commenters should submit three copies of each comment, and if commenting on both documents—the health assessment document and the exposure assessment—submit separate comments rather than combined submissions.

For the health assessment document, send comments to: Dioxin Health Assessment Comments, Technical Information Staff (8601), Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460.

ADDRESSES:

Requesting Documents

Due to the large size of both draft documents (each is over 1,000 pages in length), the documents will be available as follows:

Health Assessment Document for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds, EPA/600/BP-92/001a, 001b, 001c. (Note: The full document is 3 volumes and approx. 1,100 pages.)

OR

Risk Characterization Chapter, EPA/600/BP-92/001c. (Note: This third volume of the 3-volume set integrates health and exposure information on dioxin and related compounds; approx. 100 pages.)

AND/OR

Estimating Exposure to Dioxin-Like Compounds, EPA/600/6-88/005Ca, Cb, Cc. (Note: The full document is 3 volumes and approx. 1,300 pages.)

OR

Executive Summary Chapter of the Exposure Document, EPA/600/6-88/005Ca. (Note: This first volume of the 3-volume set summarizes the exposure information; approx. 100 pages.)

To obtain a paper copy of these draft documents, interested parties should contact the ORD Publications Center, CERI-FRN, U.S. Environmental Protection

Reassessment of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD, dioxin)

AGENCY: U.S. Environmental Protection Agency (EPA)

ACTION: As part of the Agency's reassessment of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD; hereinafter referred to as simply dioxin), two External Review Draft documents are being made available for a 120-day public review and comment period.

SUMMARY: This notice announces the availability of two External Review Draft documents for public review and comment:

1. *Health Assessment Document for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds* (EPA/600/BP-92/001a-c)
2. *Estimating Exposure to Dioxin-Like Compounds* (EPA/600/6-88/005Ca-c)

During the public comment period, public comment meetings will be convened to take formal comments on the draft documents. These meetings are being planned for the first two weeks of December at five locations: Washington, DC; New York, NY/New Jersey; Chicago, IL; Dallas, TX; and San Francisco, CA. Detailed information will be provided in a future *Federal Register* notice.

The draft documents also will be reviewed at a Science Advisory Board meeting to be held after the public comment period has ended, early next year. Information about this meeting will be published in a future *Federal Register* notice.

DATES: The draft documents will be made available on September 13, 1994. Comments must be postmarked by January 13, 1994.

DO NOT QUOTE OR CITE

EPA/600/6-88/005Cb
June 1994
External Review Draft

ESTIMATING EXPOSURE TO DIOXIN-LIKE COMPOUNDS

VOLUME II: Properties, Sources, Occurrence and Background Exposures

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Office of Health and Environmental Assessment
U.S. Environmental Protection Agency
Washington, D.C.

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FOREWORD

The Exposure Assessment Group (EAG) within the Office of Health and Environmental Assessment of EPA's Office of Research and Development has three main functions: (1) to conduct exposure assessments, (2) to review assessments and related documents, and (3) to develop guidelines for exposure assessments. The activities under each of these functions are supported by and respond to the needs of the various EPA program offices. In relation to the third function, EAG sponsors projects aimed at developing or refining techniques used in exposure assessments.

The purpose of this document is to present and evaluate information on the properties, sources, environmental levels and background exposures to dioxin-like compounds. It is the second in a three volume set addressing these compounds. The first volume provides an overall executive summary and the third volume presents methods for assessing site-specific assessments of exposure to these compounds. The three volume set serves as a final version of the 1988 draft document titled "Estimating Exposure to 2,3,7,8-TCDD." This effort represents a substantial expansion in scope to include all compounds that exhibit dioxin-like toxicity. The document is intended to be used as a companion to the health reassessment of dioxin-like compounds that the Agency is publishing concurrently. It is hoped that these documents will improve the accuracy and validity of risk assessments involving this important family of compounds.

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PREFACE

In April 1991, the U.S. Environmental Protection Agency (EPA) announced that it would conduct a scientific reassessment of the health risks of exposure to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and chemically similar compounds collectively known as dioxin. The EPA has undertaken this task in response to emerging scientific knowledge of the biological, human health, and environmental effects of dioxin. Significant advances have occurred in the scientific understanding of mechanisms of dioxin toxicity, of the carcinogenic and other adverse health effects of dioxin in people, of the pathways to human exposure, and of the toxic effects of dioxin to the environment.

In 1985 and 1988, the Agency prepared assessments of the human health risks from environmental exposures to dioxin. Also, in 1988, a draft exposure document was prepared that presented procedures for conducting site-specific exposure assessments to dioxin-like compounds. These assessments were reviewed by the Agency's Science Advisory Board (SAB). At the time of the 1988 assessments, there was general agreement within the scientific community that there could be a substantial improvement over the existing approach to analyzing dose response, but there was no consensus as to a more biologically defensible methodology. The Agency was asked to explore the development of such a method. The current reassessment activities are in response to this request.

The scientific reassessment of dioxin consists of five activities:

1. Update and revision of the health assessment document for dioxin.
2. Laboratory research in support of the dose-response model.
3. Development of a biologically based dose-response model for dioxin.
4. Update and revision of the dioxin exposure assessment document.
5. Research to characterize ecological risks in aquatic ecosystems.

The first four activities have resulted in two draft documents (the health assessment document and exposure document) for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and related compounds. These companion documents, which form the basis for the Agency's reassessment of dioxin, have been used in the development of the risk characterization chapter that follows the health assessment. The process for developing these documents consisted of three phases which are outlined in later paragraphs.

The fifth activity, which is in progress at EPA's Environmental Research Laboratory in Duluth, Minnesota, involves characterizing ecological risks in aquatic ecosystems from exposure to dioxins. Research efforts are focused on the study of organisms in aquatic food webs to identify the effects of dioxin exposure that are likely to result in significant population impacts. A report titled, *Interim Report on Data and Methods for the Assessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) Risks to Aquatic Organisms and Associated Wildlife* (EPA/600/R-93/055), was published in April 1993. This report will serve as a background document for assessing dioxin-related ecological risks. Ultimately, these data will support the development of aquatic life criteria which will aid in the implementation of the Clean Water Act.

The EPA had endeavored to make each phase of the current reassessment of dioxin an open and participatory effort. On November 15, 1991, and April 28, 1992, public meetings were held to inform the public of the Agency's plans and activities for the reassessment, to hear and receive public comments and reviews of the proposed plans, and to receive any current, scientifically relevant information.

In the Fall of 1992, the Agency convened two peer-review workshops to review draft documents related to EPA's scientific reassessment of the health effects of dioxin. The first workshop was held September 10 and 11, 1992, to review a draft exposure assessment titled, *Estimating Exposures to Dioxin-Like Compounds*. The second workshop was held September 22-25, 1992, to review eight chapters of a future draft *Health Assessment Document for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds*. Peer-reviewers were also asked to identify issues to be incorporated into the risk characterization, which was under development.

In the Fall of 1993, a third peer-review workshop was held on September 7 and 8, 1993, to review a draft of the revised and expanded Epidemiology and Human Data Chapter, which also would be part of the future health assessment document. The revised chapter provided an evaluation of the scientific quality and strength of the epidemiology data in the evaluation of toxic health effects, both cancer and noncancer, from exposure to dioxin, with an emphasis on the specific congener, 2,3,7,8-TCDD.

As mentioned previously, completion of the health assessment and exposure documents involves three phases: Phase 1 involved drafting state-of-the-science chapters and a dose-response model for the health assessment document, expanding the exposure

document to address dioxin related compounds, and conducting peer review workshops by panels of experts. This phase has been completed.

Phase 2, preparation of the risk characterization, began during the September 1992 workshops with discussions by the peer-review panels and formulation of points to be carried forward into the risk characterization. Following the September 1993 workshop, this work was completed and was incorporated as Chapter 9 of the draft health assessment document. This phase has been completed.

Phase 3 is currently underway. It includes making External Review Drafts of both the health assessment document and the exposure document available for public review and comment.

Following the public comment period, the Agency's Science Advisory Board (SAB) will review the draft documents in public session. Assuming that public and SAB comments are positive, the draft documents will be revised, and final documents will be issued.

Estimating Exposures to Dioxin-Like Compounds has been prepared by the Exposure Assessment Group of the Office of Health and Environmental Assessment, Office of Research and Development, which is responsible for the report's scientific accuracy and conclusions. A comprehensive search of the scientific literature for this document varies somewhat by chapter but is, in general, complete through January 1994.

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1. INTRODUCTION

1.1. BACKGROUND

In May of 1991, the 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 has resulted in two reports: a health reassessment document (EPA, 1994), and *Estimating Exposure to Dioxin-Like Compounds* [this three-volume report], which expands upon a 1988 draft exposure report titled, *Estimating Exposure to 2,3,7,8-TCDD* (EPA, 1988). The health and exposure reassessment documents can be used together to assess potential health risks from exposure to dioxin-like compounds. In a related area, EPA has also discussed the data and methods for evaluating risks to aquatic life from 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) (EPA, 1993).

The purpose of the exposure portion of the dioxin reassessment is to describe the causes and magnitude of background exposures, and provide site-specific procedures for evaluating the incremental exposures due to specific sources of dioxin-like compounds.

In September of 1992, EPA convened workshops to review the first public drafts of the health (EPA, 1992a) and the exposure documents (EPA, 1992b). The current draft of the exposure document incorporates changes as a result of that workshop as well as other review comments.

The exposure document is presented in three volumes. Following is a summary of the material contained in each of the three volumes:

Volume I - Executive Summary

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

Volume II - Properties, Sources, Environmental Levels, and Background Exposures

This volume presents and evaluates information on the physical-chemical properties, environmental fate, sources, environmental levels, and background human exposures to dioxin-like compounds. It summarizes and evaluates relevant information obtained from published literature searches, EPA program offices and

other Federal agencies, and published literature provided by peer reviewers of previous versions of this document. The data contained in this volume is current through 1993 with some new information published in early 1994.

Volume III - 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 soil, sediment, 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 is current through 1993 with some new information published in early 1994.

1.2. TOXICITY EQUIVALENCY FACTORS

Dioxin-like compounds are defined to include those compounds with nonzero Toxicity Equivalency Factor (TEF) values as defined in a 1989 international scheme, I-TEFs/89. This procedure was developed under the auspices of the North Atlantic Treaty Organization's Committee on Challenges of Modern Society (NATO-CCMS, 1988a; 1988b) to promote international consistency in addressing contamination involving CDDs and CDFs. EPA has adopted the I-TEFs/89 as an interim procedure for assessing the risks associated with exposures to complex mixtures of CDDs and CDFs (EPA, 1989). As shown in Table 1-1, this TEF scheme assigns nonzero values to all chlorinated dibenzo-p-dioxins (CDDs) and chlorinated dibenzofurans (CDFs) with chlorines substituted in the 2,3,7,8 positions. Additionally, the analogous brominated compounds (BDDs and BDFs) and certain polychlorinated biphenyls (PCBs, see Table 1-2) have recently been identified as having dioxin-like toxicity (EPA, 1994) and thus are also included in the definition of dioxin-like compounds. However, EPA has not assigned TEF values for BDDs, BDFs, and PCBs. In the case of PCBs, research on the applicability of the TEF approach is ongoing but there is not yet any formal EPA policy. The nomenclature adopted here for purposes of describing these compounds is summarized in Table 1-3.

Table 1-1. Toxicity Equivalency Factors (TEF) for CDDs and CDFs.

Compound	TEF
Mono-, Di-, and Tri-CDDs	0
2,3,7,8-TCDD	1
Other TCDDs	0
2,3,7,8-PeCDD	0.5
Other PeCDDs	0
2,3,7,8-HxCDD	0.1
Other HxCDDs	0
2,3,7,8-HpCDD	0.01
Other HpCDDs	0
OCDD	0.001
Mono-, Di-, and Tri-CDFs	0
2,3,7,8-TCDF	0.1
Other TCDFs	0
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
Other PeCDFs	0
2,3,7,8-HxCDF	0.1
Other HxCDFs	0
2,3,7,8-HpCDF	0.01
Other HpCDFs	0
OCDF	0.001

Source: EPA, 1989.

Table 1-2. Dioxin-Like PCBs.

IUPAC No.	Congener
77	3,3',4,4'-tetra PCB
81	3,4,4',5-tetra PCB
105	2,3,3',4,4'-penta PCB
114	2,3,4,4',5-penta PCB
118	2,3',4,4',5-penta PCB
126	3,3',4,4',5-penta PCB
156	2,3,3',4,4',5-hexa PCB
157	2,3,3',4,4',5'-hexa PCB
167	2,3',4,4',5,5'-hexa PCB
169	3,3',4,4',5,5'-hexa PCB
189	2,3,3',4,4',5,5'-hepta PCB

Source: EPA, 1992a.

Table 1-3. Nomenclature for dioxin-like compounds.

Term/Symbol	Definition
Congener	Any one particular member of the same chemical family; e.g., there are 75 congeners of chlorinated dibenzo-p-dioxins.
Homologue	Group of structurally related chemicals that have the same degree of chlorination. For example, there are eight homologues of CDDs, monochlorinated through octochlorinated.
Isomer	Substances that belong to the same homologous class. For example, there are 22 isomers that constitute the homologues of TCDDs.
Specific congener	Denoted by unique chemical notation. For example, 2,4,8,9-tetrachlorodibenzofuran is referred to as 2,4,8,9-TCDF.
D	Symbol for homologous class: dibenzo-p-dioxin
F	Symbol for homologous class: dibenzofuran
M	Symbol for mono, i.e., one halogen substitution
D	Symbol for di, i.e., two halogen substitution
Tr	Symbol for tri, i.e., three halogen substitution
T	Symbol for tetra, i.e., four halogen substitution
Pe	Symbol for penta, i.e., five halogen substitution
Hx	Symbol for hexa, i.e., six halogen substitution
Hp	Symbol for hepta, i.e., seven halogen substitution
O	Symbol for octa, i.e., eight halogen substitution
CDD	Chlorinated dibenzo-p-dioxins, halogens substituted in any position
CDF	Chlorinated dibenzofurans, halogens substituted in any position
PCB	Polychlorinated biphenyls
2378	Halogen substitutions in the 2,3,7,8 positions

Source: EPA, 1989.

The procedure relates the toxicity of 210 structurally related individual CDD and CDF congeners and is based on a limited data base of in vivo and in vitro toxicity testing. By relating the toxicity of the 209 CDDs and CDFs to the highly-studied 2,3,7,8-TCDD, the approach simplifies the assessment of risks involving exposures to mixtures of CDDs and CDFs (EPA, 1989).

In general, the assessment of the human health risk to a mixture of CDDs and CDFs, using the TEF procedure, involves the following steps (EPA, 1989):

1. Analytical determination of the CDDs and CDFs in the sample.
2. Multiplication of congener concentrations in the sample by the TEFs in Table 1-1 to express the concentration in terms of 2,3,7,8-TCDD equivalents (TEQs).
3. Summation of the products in Step 2 to obtain the total TEQs in the sample.
4. Determination of human exposure to the mixture in question, expressed in terms of TEQs.
5. Combination of exposure from step 4 with toxicity information on 2,3,7,8-TCDD to estimate risks associated with the mixture.

Samples of this calculation for several environmental mixtures are provided in EPA (1989). Also, this procedure is demonstrated in Volume III of this assessment in the context of the demonstration of the stack emission source category. The seventeen dioxin-like congeners are individually modeled from stack to exposure site. TEQ concentrations are estimated given predictions of individual congener concentrations using Steps 2 and 3 above.

1.3. OVERALL COMMENTS ON THE USE OF THE DIOXIN EXPOSURE DOCUMENT

Users of the dioxin exposure document should recognize the following:

1. This document does not present detailed procedures for evaluating multiple sources of release. However, it can be used in two ways to address this issue. Incremental impacts estimated with procedures in Volume III can be compared to background exposure estimates which are presented in Volume II. This would be a way of comparing the incremental impact of a specific source to an individual's total exposure. If the releases

from multiple sources behave independently, it is possible to model them individually and then add the impacts. For example, if several stack emission sources are identified and their emissions quantified, and it is desired to evaluate the impact of all sources simultaneously, then it may be possible to model each stack emission source individually and then sum the concentrations and depositions at points of interest in the surrounding area.

2. The procedures and estimates presented in this three-volume exposure document best serve as general examples for evaluating exposures to dioxin-like compounds, rather than specific assessments. This document was not generated for purposes of supporting any specific regulation. Rather, it is intended to be a general information source which Agency programs can adopt or modify as needed for their individual purposes. For example, the demonstration scenarios of Volume III were not crafted as Agency policy on "high end" or "central tendency" scenarios for evaluating land contamination, stack emissions, or effluent discharges. Rather, they were designed to illustrate the site-specific methodologies in Volume III.

3. The understanding of the exposure to dioxin-like compounds continues to expand. Despite being one of the most studied groups of organic enivronmental contaminants, new information is generated almost daily about dioxin-like compounds. This document is considered to be current through 1993, with some information published early in 1994 included as well. Section IV of Volume I, Executive Summary, discusses research needs for dioxin exposure evaluation.

1.4. ORGANIZATION OF VOLUME II

The scope of the five remaining chapters and three appendices of this report are as follows:

Chapter 2, Physical and Chemical Properties and Fate, summarizes available information on the physical/chemical properties and environmental fate of the dioxin-like compounds.

Chapter 3, Sources, summarizes information about the known sources from which these compounds may enter the environment and provides estimates of annual releases to the environment from various sources.

Chapter 4, Environmental Levels, summarizes information on the concentrations of dioxin-like compounds found in various media (i.e., air, water, food, soil, and sediment).

Chapter 5, Background Exposures, provides estimates of the background exposures to dioxin-like compounds from environmental media and foods.

Chapter 6, Pharmacokinetics, summarizes information about uptake and distribution of dioxin-like compounds in the body and presents pharmacokinetic models to predict blood and tissues resulting from exposure. In addition, measured CDD/CDF concentrations in blood and tissues are used to back-calculate associated exposure levels.

Appendix A, Tables of Chemical Properties, presents congener-specific data for a variety of chemical properties.

Appendix B, Tables of Media Levels, summarizes congener-specific monitoring data for congeners in various media.

Appendix C, Bioavailability of Dioxins, summarizes data on the bioavailability of 2,3,7,8-TCDD from environmental matrices.

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2. PHYSICAL AND CHEMICAL PROPERTIES AND FATE

2.1. INTRODUCTION

This chapter summarizes available information regarding the physical and chemical properties and fate of the CDDs, CDFs, BDDs, BDFs, and coplanar PCBs, with an emphasis on the subset of these chemicals defined as dioxin-like in Chapter 1. Physical/chemical properties addressed in this chapter 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 covered in the companion volume to this report, Volume 3: Site-Specific Assessment Procedures.

Knowledge of physical and chemical properties is essential to understanding and modeling the environmental transport and transformation of organic compounds such as the dioxin-like compounds. The properties most important for understanding the environmental behavior of the dioxin and dioxin-like compounds appear to be water solubility (WS), vapor pressure (VP), octanol/water partition coefficient (K_{ow}), organic carbon partition coefficient (K_{oc}), and photochemical quantum yield. The ratio of VP to WS (VP/WS) can be used to calculate the Henry's Law constant (H_c) for dilute solutions of organic compounds. Henry's Law constant is an index of partitioning for a compound between the atmospheric and the aqueous phase (Mackay et al., 1982).

To maximize and optimize the identification of information on the physical/chemical properties of these compounds, a thorough search of the recent literature was conducted. A computer literature search was conducted using the on-line Chemical Abstracts (CA) data base maintained by the Scientific Technical Network (STN). Printed abstracts were obtained and screened, and selected literature were retrieved and critically evaluated. The most definitive value for each physical/ chemical property for each congener was selected. The evaluation method used to select the most definitive physical/chemical property values is detailed in Section 2.3. The property values obtained from the scientific literature are summarized in Appendix A. Sections 2.4 and 2.5 present the property values for the dioxin-like compounds that are considered to be the most definitive. These values are

utilized in the modeling equations in the companion volume to this report, Volume 3-Site-Specific Assessment Procedures. Appendix A lists all reported property values for the CDDs, CDFs, and coplanar PCBs. Where technically feasible, estimation procedures have been used to provide values where measured data are not available. For those compounds for which data could not be found and estimates are not appropriate, the field is left blank and a congener group average is presented as the property value for that congener group.

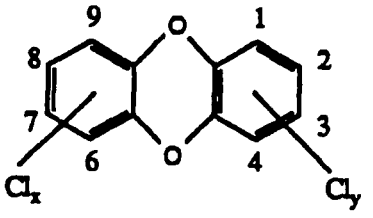
The values suggested in this document as most definitive are, in the authors' opinion, the best values derivable from current data. Since the document has undergone extensive review inside the Agency, by scientific community outside the Agency, and by the Science Advisory Board, the values can be interpreted as generally representative of the Agency and scientific community. The authors recommend that document users consider the values as defaults in the sense that users are encouraged to accept them as a starting point but should feel free to modify them as new data become available.

Brief summaries of the recent and relevant scientific literature on the environmental fate of the polychlorinated and polybrominated dibenzodioxins, dibenzofurans, and biphenyls are provided in Sections 2.6 and 2.7.

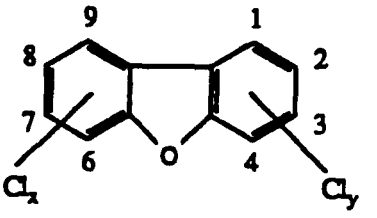
2.2. GENERAL INFORMATION

Polychlorinated dibenzodioxins (CDDs), polychlorinated dibenzofurans (CDFs), and polychlorinated biphenyls (PCBs) are chemically classified as halogenated aromatic hydrocarbons. CDDs and CDFs can be formed as unintentional by-products through a variety of chemical reactions and combustion processes. Both compound classes have a triple-ring structure that consists of two benzene rings connected by a third oxygenated ring. For CDDs, the benzene rings are connected by a pair of oxygen atoms. CDFs are connected via a single oxygen atom. (See structures below.) PCBs are a class of compounds formed by the chlorination of a biphenyl molecule.

There are 75 possible different positional congeners of CDDs and 135 different congeners of CDFs. Likewise, there are 75 possible different positional congeners of BDDs and 135 different congeners of BDFs. (See Table 2-1.) The basic structure and numbering of each chemical class is shown below.



PCDDs



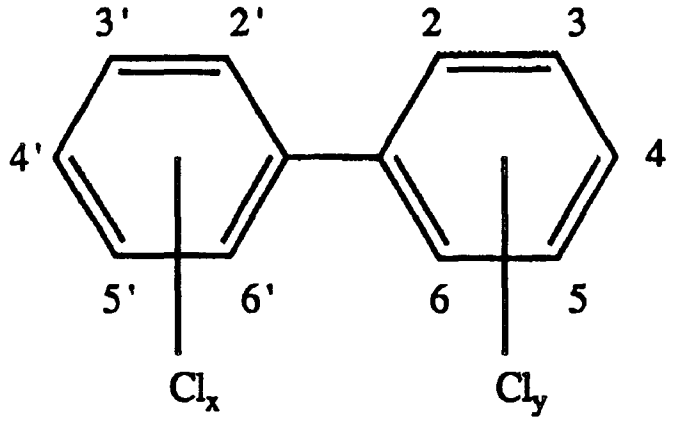
PCDFs

X = 1 to 4, Y = 1 to 4, X + Y $\geq$ 1

Table 2-1. Possible Number of Positional CDD (or BDD) and CDF (or BDF) Congeners

Halogen Substitution	Number of Congeners		
	CDDs (or BDDs)	CDFs (or BDFs)	PCBs
Mono	2	4	3
Di	10	16	12
Tri	14	28	24
Tetra	22	38	42
Penta	14	28	46
Hexa	10	16	42
Hapta	2	4	24
Octa	1	1	12
Nona	0	0	3
Deca	0	0	1

There are 209 possible PCB congeners. (See Table 2-1.) The physical/chemical properties of each congener vary according to the degree and position of chlorine substitution. The list of coplanar PCBs can be found in Table 1-2. PCBs assume a coplanar structure when the two benzene rings rotate into a position where the two rings are in the same plane. The PCBs assume a dioxin-like structure when the substituent chlorines occupy the 3, 3', 4, 4', 5, or 5' positions, or possibly, one of the 2 or 2' positions, and the structure is not hindered from assuming the preferred planar configuration. The basic structure and numbering of each chemical class is shown below.



X = 1 to 5, Y = 1 to 5, X + Y $\geq$ 1

2.3. PHYSICAL/CHEMICAL PROPERTY EVALUATION METHODOLOGY

As discussed above, a thorough search of the recent published scientific literature was conducted to maximize and optimize the identification of measured physical/chemical properties. For the purpose of identifying the most definitive of two or more physical/chemical property values reported in the literature for a given dioxin-like compound, a ranking methodology was developed to evaluate the degree of confidence in the reported values. A property value with a ranking of 1 is considered to have the highest level of confidence; a property value with a ranking of 6 is considered to have the lowest level of confidence. The ranking scheme assumes that measured values are more definitive than estimated values. The ranking scheme is based on five ranking criteria or factors. These factors are described below:

Factor 1: *Confirmation.* Value, measured or derived, confirmed by at least one other laboratory, or different experimental technique. Confirmation was assumed if the reported values were within 50 percent of the highest value (within 5 percent for values reported in logarithmic units).

Factor 2: *Measurement Technique.* Direct measurement technique used. No measurements reported less than 10 times the method detection limit.

Factor 3: *GLP Followed.* Good Laboratory Practice was followed in the experimental work. This includes the use of traceable, pure standards; sensitive, selective detection technique was employed; repeatability of measurements demonstrated; all experimental details sufficiently documented so others could reproduce experiments; sources of determinate error considered - error analysis conducted.

Factor 4: *Derived Value.* Value derived from other directly measured physical/chemical properties by use of known physical/chemical relationships developed for structurally similar chemicals (e.g., other dioxin, furan, and PCB congeners, multiple-ring halogenated compounds). The input value (i.e., the independent variable) used to derive the property value of interest from the equation (i.e., the physical/chemical relationship) is a directly measured value.

Factor 5: *Estimated Value.* Value estimated using a physical/chemical relationship that was developed using estimated values or a combination of estimated and measured values; this includes QSAR (Quantitative Structure Activity Relationship) methods. Also includes values derived from other directly measured physical/chemical properties by use of known physical/chemical relationships developed, in large part, for structurally dissimilar compounds.

Although this ranking scheme is subjective in nature, it is a reasonable method for identifying the most definitive physical/chemical property value. The ranking scheme has several advantages. First, it identifies where more work is needed to obtain a more definitive p-chem property value. Second, it allows for later adjustments in these values when more definitive studies are conducted. A low ranking for a study does not mean

that a particular reported value is incorrect - only that insufficient evidence exists to determine its accuracy. The ranking scheme is as follows:

Rank 1: Confirmed Measured Values. The reported value has met Factors 1, 2, and 3. (See Table 2-2.) This value is considered definitive.

Rank 2: Unconfirmed Measured Values. The reported value has met Factors 2 and 3. The value is considered accurate; it could be definitive subject to confirmation.

Rank 3: Confirmed Derived Values. The reported value has met Factors 1, 3, and 4. The value is considered to be a close approximation.

Rank 4: Unconfirmed Derived Value. The reported value has met Factors 3 and 4. The value is considered to be an approximation.

Rank 5: Estimated Value. The reported value has met Factor 5 only. The value is considered to be an "order-of-magnitude" estimate.

Table 2-2. Ranking Scheme for P-Chem Property Evaluation

Ranking	Factors				
	1	2	3	4	5
1	✓	✓	✓	x	x
2	x	✓	✓	x	x
3	✓	x	✓	✓	x
4	x	x	✓	✓	x
5	x	x	x	x	✓

Notes: ✓ indicates all specifications of the Factor have been met.
x indicates the specifications of the Factor have not been met, or the Factor does not apply.

If two or more values have the same ranking, then the value that has been peer reviewed by other EPA offices, other government agencies, or scientific data bases (e.g., the Syracuse Research Corporation Environmental Fate Data Bases) and chosen by that office, agency, or data base as the most accurate, was deemed to be the most definitive value for this document. If two or more values with the same ranking have not been peer reviewed as above, typically the most current value was chosen as the most definitive value. This decision was made on the assumption that the most current value would have been developed by the latest scientific method. If two or more values had the same ranking, then some evaluation of the techniques used to derive the value were also considered in choosing the more definitive value. The ranking of the literature can be found in Table A-2 in Appendix A. Table 2-3 lists the property values for the dioxin-like compounds that are considered to be most definitive.

2.4. PHYSICAL/CHEMICAL PROPERTIES - CHLORINATED COMPOUNDS

Limited research has been conducted to determine physical and chemical properties of CDFs and CDDs. The congeners having 2,3,7,8-chlorination have received the most attention, with 2,3,7,8,-TCDD being the most intensely studied compound. All 2,3,7,8-substituted congeners are now available commercially, but many of these isomers have not been prepared in pure form. Some of the isomers that have been prepared may not be available in sufficient quantities for testing. Another factor which is likely to have limited research on these compounds is the high toxicity of these compounds, which necessitates extreme precautions to prevent potential adverse effects.

2.4.1. Water Solubility

Although water solubility data are not directly used in the exposure scenario equations in Volume 3, water solubility data can be used to estimate Henry's Law constants (using the VP/WS ratio technique) that are used in the equations in Volume 3. Very few measured water solubility values are available in the literature. Marple et al. (1986a) reported the water solubility of 2,3,7,8-TCDD as 19.3 ± 3.7 parts per trillion (nanograms per liter, ng/L) at 22°C. Marple et al. (1986a) used a procedure of equilibrating thin films of resublimed 2,3,7,8-TCDD with a small volume of water followed by gas chromatography (GC) analysis with 63Ni electron capture detection. Other water

Table 2-3. P-Chem Properties for the Dioxin-Like Congeners

Chemical CAS No.	Melting Point C°[a]	Melting Point Ref.	Water Solubility mg/l[a]	WS Temp.	WS Ref. [R][b]	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref. [R][b]	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref. [R][b]	Log K_{ow}[a]	Log K_{ow} Ref. [R][b]	Log K_{oc}[a]	Log K_{oc} Ref. [R][b]	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Tetrachlorodibenzo-p-dioxins (MW=321.98)																
2,3,7,8-TCDD 1746-01-6	305-306	9	1.93E-05	22	1,2 [1]	7.40E-10	25	2,3 [2]	(1.6E-05)	2,3 [4]	6.64	2,4 [1]	6.4	50 [1]	2.2E-03[c] 3.3E-02[c]	22 30
Congener Group Average			(3.5E-04)	25	20	(8.1E-07)	25	20	(3.2E-05)	20	(6.4)	20	(6.2)	20		
Pentachlorodibenzo-p-dioxins (MW=356.42)																
1,2,3,7,8-PeCDD 40321-76-4	240-241	9				9.48E-10	25	33 [4]			6.64	10 [2]				
Congener Group Average			(1.2E-04)	20	20	(7.3E-10)	25	20	(2.6E-06)	20	(6.6)	20	(5.7)	20		
Hexachlorodibenzo-p-dioxins (MW=390.87)																
1,2,3,4,7,8-HxCDD 39227-28-6	273-275	9	4.40E-06	20	6 [2]	1.01E-10	25	33 [4]	(1.2E-05)	19 [4]	7.79	8 [4]	5.92	45 [2]	1.1E-04[d]	23
1,2,3,6,7,8-HxCDD 57653-85-7	285-286	9				(3.6E-11)	25	9 [5]								
1,2,3,7,8,9-HxCDD 19408-74-3	243-244	9				(4.9E-11)	25	9 [5]								
Congener Group Average			(4.4E-06)	20	20	(5.9E-11)	25	20	(1.2E-05)	20	(7.3)	20	(5.9)	20		
Heptachlorodibenzo-p-dioxins (MW=425.31)																
1,2,3,4,6,7,8-HpCDD 35822-46-9	264-265	9	2.40E-06	20	6 [2]	3.21E-11	25	33 [4]	(7.5E-06)	19 [4]	8.20	8 [4]			1.53E-05[d]	23
Congener Group Average			(2.4E-06)	20	20	(3.2E-11)	25	20	(7.5E-06)	20	(8.2)	20				
Octachlorodibenzo-p-dioxins (MW=460.76)																

Table 2-3. P-Chem Properties for the Dioxin-Like Congeners (continued)

Chemical CAS No.	Melting Point C[a]	Melting Point Ref.	Water Solubility mg/l[a]	WS Temp.	WS Ref. [R][b]	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref. [R][b]	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref. [R][b]	Log K_{ow}[a]	Log K_{ow} Ref. [R][b]	Log K_{oc}[a]	Log K_{oc} Ref. [R][b]	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,3,4,6,7,8,9-OCDD 3268-87-9	325-326	6	7.4E-08	25	5 [2]	8.25E-13	25	9 [2]	(7.0E-09)	5 [4]	7.59	5 [2]			2.26E-05[d]	23
Tetrachlorodibenzofurans (MW=305.98)																
2,3,7,8-TCDF 51207-31-9	227-228	21	4.19E-04	22.7	11 [2]	8.96E-09	25	33 [4]	(8.6E-06)	19 [4]	6.53	10 [2]				
Congener Group Average			(4.2E-04)	22.7	20	(2.5E-08)	25	20	(8.6E-06)	20	(6.2)	20				
Pentachlorodibenzofurans (MW=340.42)																
1,2,3,7,8-PeCDF 57117-41-6	225-227	21				2.72E-09	25	33 [4]			6.79	10 [2]				
2,3,4,7,8-PeCDF 57117-31-4	196-196.5	21	2.36E-04	22.7	11 [2]	3.29E-09	25	33 [4]	(6.2E-06)	19 [4]	6.92	10 [2]				
Congener Group Average			(2.4E-04)	22.7	20	(2.7E-09)	25	20	(6.2E-06)	20	(6.4)	20				
Hexachlorodibenzofurans (MW=374.87)																
1,2,3,4,7,8-HxCDF 70648-26-9	225.5-226.5	21	8.25E-06	22.7	11 [2]	(2.4E-10)	25	21 [5]	(1.4E-05)	19 [5]					6.96E-04[c]	25
1,2,3,6,7,8-HxCDF 57117-44-9	232-234	21	1.77E-05	22.7	11 [2]	(2.2E-10)	25	21 [5]	(6.1E-06)	19 [5]						
1,2,3,7,8,9-HxCDF 72918-21-9	246-249	21														
2,3,4,6,7,8-HxCDF 60851-34-5	239-240	21				(2.0E-10)	25	21 [5]								
Congener Group Average			(1.3E-05)	22.7	20	(2.8E-10)	25	20	(1.0E-05)	20						

Table 2-3. P-Chem Properties for the Dioxin-Like Congeners (continued)

Chemical CAS No.	Melting Point C°[a]	Melting Point Ref.	Water Solubility mg/l[a]	WS Temp.	WS Ref. [R][b]	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref. [R][b]	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref. [R][b]	Log K_{ow}[a]	Log K_{ow} Ref. [R][b]	Log K_{oc}[a]	Log K_{oc} Ref. [R][b]	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Heptachlorodibenzofurans (MW=409.31)																
1,2,3,4,6,7,8-HpCDF 67562-39-4	236-237	21	1.35E-06	22.7	11 [2]	1.33E-10	25	33 [4]	(5.3E-05)	19 [4]	7.92	10 [2]				
1,2,3,4,7,8,9-HpCDF 55673-89-7	221-223	21				1.07E-10	25	33 [4]								
Congener Group Average			(1.4E-06)	22.7	20	(9.9E-11)	25	20	(5.3E-05)	20	(7.9)	20				
Octachlorodibenzofurans (MW=444.76)																
1,2,3,4,6,7,8,9-OCDF 39001-02-0	258-260	21	(1.2E-06)	25	11 [2]	3.75E-12	25	21 [2]	(1.9E-06)	19 [4]	8.78	8 [4]				
Tetrachloro-PCB (MW=291.99)																
3,3',4,4'-TCB 32598-13-3	453	17	5.49E-04	25	13 [1]	1.37E-07	25	13 [4]	9.40E-05	13 [2]	6.21	15 [2]				
3,4,4',5-TCB 70362-50-4	(410)	17	8.43E-06	25	41 [2]	2.80E-10	25	41 [2]	1.28E-04	41 [4]	6.4	15 [5]				
Pentachloro-PCB (MW=326.44)																
2,3,3',4,4'-PeCB 32598-14-4	(398)	17	(1.9E-03)	25	35 [5]	(5.9E-06)	25	18 [5]	(9.9E-05)	35 [5]	(6.6)	15 [5]				
2,3,4,4',5-PeCB 74472-37-0	(392)	17	3.69E-06	25	41 [2]	5.96E-10	25	41 [2]	6.9E-05	41 [4]	(6.6)	15 [5]				
2,3',4,4',5-PeCB 31508-00-6	378	17	4.27E-06	25	41 [2]	8.45E-10	25	41 [2]	8.5E-05	41 [4]	7.12	31 [4]	5.7	42 [4]		
3,3',4,4',5-PeCB 57465-28-8	(398)	17	(1.0E-03)	25	17 [5]	(2.9E-06)	25	18 [5]	(5.4E-05)	35 [5]	(6.9)	15 [5]				

Table 2-3. P-Chem Properties for the Dioxin-Like Congeners (continued)

Chemical CAS No.	Melting Point C*[a]	Melting Point Ref.	Water Solubility mg/l[a]	WS Temp.	WS Ref. [R][b]	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref. [R][b]	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref. [R][b]	Log K_{ow}[a]	Log K_{ow} Ref. [R][b]	Log K_{oc}[a]	Log K_{oc} Ref. [R][b]	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Hexachloro-PCB (MW=360.88)																
2,3,3',4,4',5-HxCB 38380-08-4	(414)	17	7.44E-07	25	41 [2]	(1.4E-06)	25	18 [5]	8.7E-04	43 [4]	7.14	14 [3]				
2,3,3',4,4',5'-HxCB 69782-90-7	(414)	17	(3.6E-04)	25	17 [5]	(1.2E-06)	25	18 [5]	5.8E-04	43 [4]	7.16	14 [3]				
2,3',4,4',5,5'-HxCB 52663-72-6	(408)	17	(3.6E-04)	25	17 [5]	(2.0E-06)	25	18 [5]	(1.1E-04)	35 [5]	7.17	14 [3]				
3,3',4,4',5,5'-HxCB 32774-16-6	(485)	17	(4.2E-05)	25	35 [5]	(1.5E-06)	25	20 [5]	(6.5E-05)	35 [5]	7.47	14 [3]				
Heptachloro-PCB (MW=396.33)																
2,3,3',4,4',5,5'-HpCB 39635-31-9	(431)	17	(4.5E-05)	25	35 [5]	(3.0E-07)	25	18 [5]	(6.6E-05)	35 [5]	(7.7)	15 [5]				

Footnote References

[a] Values are presented as they appeared in the referenced article. Subcooled liquid values were converted to solid values (33). Values in ( ) are calculated.
[b] [R] is the ranking of the value from the cited reference.
[c] Tested in solution of water:acetonitrile (1:1 v/v) at 313 nm.
[d] Tested in solution of water:acetonitrile (2:3 v/v) at 313 nm.
[e] Tested in vapor phase at 250-360 nm.

1. Murphy et al. (1986a)
2. USEPA (1990)
3. Podoll et al. (1986)
4. Murphy et al. (1986b)
5. Shiu et al. (1988)
6. Friesen et al. (1985)
8. Burkhard and Kuehl (1986)
9. Rordorf (1987)
10 Sijm et al. (1989)
11. Friesen et al. (1990b)
13. Dunnivant and Elzerman (1988)
14. Risby et al. (1990)
15. Hawker and Connell (1988)
16. Sabljic and Gusten (1989)
17. Abramowitz and Yalkowsky (1990)
18. Foreman and Bidleman (1985)
19. Calculated by the VP/WS ratio technique
20. Average of all literature values (measured and calculated) within a homologue group
21. Rordorf (1989)
22. Dulin et al. (1986)
23. Choudhry and Webster (1987)
25. Choudhry et al. (1990)
30. Orth et al. (1989)
33. Hitzer and Hites (1988)
35. Dunnivant et al. (1992)
41. Murphy et al. (1987)
42. EPRI (1990)
43. Murphy et al. (1983)
45. Webster et al. (1986)
50. Murphy et al. (1987)

solubility values for 2,3,7,8-TCDD have been reported in the literature and are summarized in U.S. EPA (1990). Values ranging from 7.9 ng/L to 483 ng/L are reported in U.S. EPA (1990) with 19.3 ng/L selected as the recommended value. The value of 19.3 ng/L was confirmed by Marple et al. (1987) using both radio-labeled and unlabeled 2,3,7,8-TCDD. Marple et al. (1987) reported values of 10.6 ng/L and 10.4 ng/L for the labeled and unlabeled compounds respectively. Because the value of 19.3 ng/L was confirmed by other techniques and was recommended by U.S. EPA (1990), it was chosen as the most definitive value.

Friesen et al. (1985) and Shiu et al. (1988) used HPLC generator column techniques to measure the water solubilities of a series of chlorinated dioxins (1,2,3,4-, 1,2,3,7-, and 1,3,6,8-TCDD; 1,2,3,4,7-PeCDD; 1,2,3,4,7,8-HxCDD; 1,2,3,4,6,7,8-HpCDD; and OCDD). Reported water solubilities ranged from 320 ng/L to 0.074 ng/L for the 1,2,3,7-TCDD and OCDD congeners, respectively. The only congener with more than one value was OCDD. The value of 0.074 ng/L (Shiu et al., 1988) was chosen because it was the most current. Friesen et al. (1990) used a gas chromatography/mass spectrometry detection (GC/MSD) generator column technique to measure the water solubilities of a series of chlorinated furans (2,3,7,8-TCDF; 2,3,4,7,8-PeCDF; 1,2,3,6,7,8- and 1,2,3,4,7,8-HxCDF; and 1,2,3,4,6,7,8-HpCDF) and reported a decrease in water solubility with an increase in the number of chlorine substituents. The reported water solubility values ranged from 1.37×10^{-9} mol/L (419 ng/L) for the 2,3,7,8-TCDF isomer to 3.30×10^{-12} mol/L (1.35 ng/L) for the 1,2,3,4,6,7,8-HpCDF congener. The dioxin-like furans only had one value reported for water solubility.

Values for the various congener groups ranged as follows: TCDDs 0.47-596 ng/l, PeCDDs 120-166 ng/l, HxCDDs 4.4 ng/l, HpCDDs 2.4 ng/l, OCDD 0.074-0.4 ng/l, TCDFs 4.2 ng/l, PeCDFs 236 ng/l, HxCDFs 8.2-17.7 ng/l, HpCDFs 1.35 ng/l, and OCDF 1.16 ng/l. The range for CDDs covers nearly four orders of magnitude, and for the CDFs two orders of magnitude.

The reported water solubility values for the coplanar PCB compounds are comparable to those for the CDD and CDF compounds. The reported values range from 11,400 ng/L for 3,3',4,4'-TeCB to 0.74 ng/L for 2,3,3',4,4',5-HxCB. Measured water solubility data chosen as the most definitive were those reported by Dunnivant and Elzerman (1988) and Murphy et al. (1987). The value of 549 ng/L (Dunnivant and

Elzerman, 1988) for 3,3',4,4'-TCB was confirmed by Dickhut et al. (1986) with a value of 569 ng/L. Therefore, 549 ng/L was chosen as the most definitive value for 3,3',4,4'-TCB. Murphy et al. (1987) proved the only measured values for the other congeners.

For those compounds without reported measured water solubility values, estimations were calculated by the congener group-average method. For example, for the tetra-chlorinated dioxins, values reported in the literature were averaged to yield an estimated water solubility value for the tetra-chlorinated dioxin congener group. A similar procedure was used to develop the average value for each of the other CDD and CDF congener groups. The most definitive value for each isomer was used to derive the congener group average. Estimating the water solubility values from measured log K_{ow} values using the estimation procedure of Lyman et al. (1982) did not yield satisfactory results; the estimated water solubilities for 2,3,7,8-TCDD and 1,3,6,8-TCDD were at least two orders of magnitude greater than the measured values in Tables 2-3 and A-1. Compounds that have water solubility values in the ranges reported for these chlorinated compounds are considered to have very poor solubility in water.

2.4.2. Vapor Pressure

Vapor pressure data are not directly used in the exposure scenario equations in Volume 3. However, vapor pressure data can be used to estimate Henry's Law constant using the VP/WS ratio technique. Very few measured vapor pressure values are available in the literature for the CDDs and CDFs. The majority of the measured vapor pressures are for the 2,3,7,8-substituted compounds.

U.S. EPA (1990) presented the range of measured vapor pressure data for 2,3,7,8-TCDD and selected a recommended value of 7.4×10^{-10} mm Hg at 25°C. This value was reported by Podoll et al. (1986) who used radiolabeled 2,3,7,8-TCDD and a gas saturation technique with combustion to $^{14}CO_2$. Rordorf (1987, 1989) reported a higher vapor pressure value for 2,3,7,8-TCDD, 1.49×10^{-9}mm Hg. SRC (1991) reported this same value by extrapolating the vapor pressures measured by Schroy et al. (1985) at four higher temperatures, 30°, 55°, 62°, and 71°C. The value recommended in U.S. EPA (1990) is reported in Table 2-3.

Rordorf (1987, 1989) reported experimental vapor pressure values for 1,2,3,4-TCDD (4.8×10^{-8} mm Hg), OCDD (8.25×10^{-13}mm Hg), and OCDF

(3.75×10^{-12} mm Hg) (Table A-1). These values were chosen as the most definitive because they were the most current directly measured values. Rordorf (1987, 1989) used a gas-flow method in a saturation oven, with integrated gas chromatographic analysis, to measure vapor pressure values for ten CDDs and four CDFs. Rordorf (1987, 1989) also used a vapor pressure correlation method to predict the vapor pressures of 15 other CDDs and 55 CDFs based on the measured vapor pressures for the 10 CDDs, 4 CDFs, and the deduced boiling point and enthalpy data for the larger series of CDDs and CDFs. Measured boiling point and enthalpy data are in good agreement with the deduced data used in the correlation method. Of the CDDs studied by Rordorf (1987, 1989), only three of the ten, 1,2,3,4-TCDD, 2,3,7,8-TCDD, and OCDD, are in the dioxin-like compound group of chemicals studied in this report. The other CDDs with measured values were monochloro-, dichloro-, and trichloro-dibenzo-p-dioxins.

Eitzer and Hites (1988) reported experimental vapor pressure values for several of the dioxin-like compounds utilizing GC capillary column retention time data. The values were reported as subcooled liquids and then converted to solid-phase vapor pressures. The solid-phase vapor pressures ranged from 2.16×10^{-12} mm Hg to 9.48×10^{-10} mm Hg for the CDDs and from 1.07×10^{-10} mm Hg to 8.96×10^{-9} for the CDFs. The values from Eitzer and Hites (1988) were considered the most definitive, except for OCDD, because they were the only values that were derived (i.e., Rank 4); all other values were estimated (i.e., Rank 5).

Values reported for the congeners within various congener groups are as follows:

Congener Group	Vapor Pressure Range (mm Hg)		
TCDD	7.4×10^{-10}	to	4.03×10^{-6}
PeCDD	4.35×10^{-10}	to	9.48×10^{-10}
HxCDD	3.60×10^{-11}	to	1.01×10^{-10}
HpCDD	5.62×10^{-12}	to	3.21×10^{-11}
OCDD	8.25×10^{-13}	to	6.54×10^{-8}
TCDF	8.96×10^{-9}	to	3.98×10^{-8}
PeCDF	1.50×10^{-9}	to	4.28×10^{-9}
HxCDF	1.80×10^{-10}	to	5.70×10^{-10}
HpCDF	3.53×10^{-11}	to	1.33×10^{-10}
OCDF	3.75×10^{-12}		

The range for CDDs covers over six orders of magnitude, and for the CDFs, four orders of magnitude.

The measured vapor pressure values reported for the coplanar PCBs are comparable to those reported for the CDD and CDF compounds; the estimated values are higher by several orders of magnitude. (See Table 2-3.) The directly measured values of Murphy et al. (1987) and the derived value of Dunnivant and Elzerman (1988) were considered the most definitive. All other values were estimated. The values reported in Tables 2-3 and A-1 by Foreman and Bidleman (1985) are an average of the OV-101 RI and Dexsil 410 RI correlation methods because both methods were determined to be equally valid. As with the other groups, the vapor pressures of the PCBs decrease with an increase in the number of chlorine substituents. The highest reported value for the coplanar PCBs is 2.90×10^{-6} mm Hg for 3,3',4,4',5-PeCB, and the lowest value reported is 2.80×10^{-10} mm Hg for 3,4,4',5-TeCB.

Estimated vapor pressure values for those CDDs and CDFs for which measured values were not found in the literature were calculated by the congener group-average method using the literature-reported values within a congener group. For example, the literature values for the TCDDs were averaged to obtain an estimated vapor pressure assumed to apply to the TCDD congeners that did not have literature values. A similar procedure was used to develop a congener-average for each of the other congener groups. The most definitive value for each isomer was used to derive the congener group average. Compounds with vapor pressures in the ranges reported for these compounds are considered to have very low vapor pressures.

2.4.3. Henry's Law Constant

Henry's Law constant data are used in Volume 3 to estimate the volalitization of the dioxin-like compounds from soil. They are also utilized in estimating the vapor-phase bioconcentration factor from air to plant leaves. Directly measured data for Henry's Law constant have been reported for only two compounds, one TCDD congener, and one PCB congener. The measured values for 1,3,6,8-TCDD, 6.81×10^{-5} atm-m^3/mol (Webster et al., 1985), and for 3,3',4,4'-PCB, 9.4×10^{-5} atm-m^3/mol (Dunnivant and Elzerman, 1988) were determined by the gas-purging technique. These two values were considered the most definitive. Other values reported in the literature for CDDs, CDFs, and PCBs were calculated by the vapor pressure/water solubility (VP/WS) ratio technique or by structure-

activity relationship techniques. A derived VP/WS ratio value, Rank 4, was determined to be more definitive than an estimated value, Rank 5.

Group-average Henry's Law constants were estimated for each congener group based on the reported data for that group. The Henry's Law constant values for the PCBs are similar to those for the CDDs and CDFs.

Lyman et al. (1982) offers guidelines, though not specific to these compounds, for comparing the degree to which organic compounds volatilize from water. These guidelines suggest that volatilization of polycyclic aromatic hydrocarbons and halogenated aromatics (which includes all the dioxin-like compounds) from water represents a significant transfer mechanism from the aqueous to the atmospheric phase.

2.4.4. Octanol/Water Partition Coefficient

The octanol/water partition coefficient is used in several exposure estimation procedures in Volume 3. It is used to estimate log K_{oc} when measured data are not available, and it is utilized in estimating the root concentration factor (RCF). The RCF is used to estimate the uptake of contaminants by plant roots. Log K_{ow} is also used to estimate the vapor-phase bioconcentration factor from air to plant leaves.

Marple et al. (1986b) reported the octanol/water partition coefficient of 2,3,7,8-TCDD as 4.24 ($\pm$ 2.73) x 10^6 at 22 $\pm$ 1°C, yielding a log K_{ow} of 6.64 (Table A-1). Two similar experimental techniques were used, but the more reliable method involved equilibration of water-saturated octanol, containing the 2,3,7,8-TCDD, with octanol-saturated water, over 6 to 31 days. U.S. EPA (1990) reported that the available low K_{ow} data ranged from 6.15 to approximately 8.5. The 6.64 value reported by Marple et al. (1988b) was the value recommended in that report. The 6.64 value was confirmed by Sijm et al. (1989) with a value of 6.42, and by Marple et al. (1987) with a value of 6.69; therefore, a log K_{ow} value of 6.64 was considered the most definitive.

Burkhard and Kuehl (1986) used reverse-phase High Pressure Liquid Chromatography (HPLC) and Liquid Chromatography/Mass Spectrometry (LCMS) detection to determine octanol/water partition coefficients for 2,3,7,8-TCDD and a series of seven other tetrachlorinated planar molecules, including three other TCDD isomers (1,2,3,4-TCDD; 1,3,7,9-TCDD; 1,3,6,8-TCDD), 2,3,7,8-TCDF, and 3,3',4,4'-tetrachlorobiphenyl.

The log K_{ow} values for the four TCDD isomers ranged from 7.02 to 7.20. The log K_{ow} for 2,3,7,8-TCDF was 5.82, and the log K_{ow} for 3,3',4,4'-TCB was 5.81.

Burkhard and Kuehl (1986) also re-evaluated data on 13 CDDs and CDFs previously reported by Sarna et al. (1984) under similar experimental techniques. In the re-evaluation, Burkhard and Kuehl (1986) used experimental rather than estimated log K_{ow} values in correlations with gas chromatographic retention times. This approach yielded log octanol-water partition coefficients ranging from about 4.0 for the nonchlorinated parent molecules to about 8.78 for the octa-chlorinated compounds, much lower than the values originally reported by Sarna et al. (1984).

Sijm et al. (1989) used a slow stirring method to obtain log K_{ow} values for 73 CDD and CDF congeners. Values ranged from 6.10 to 7.92.

The most definitive values chosen were either a directly measured value or the most current derived value. Only 2,3,7,8-TCDD had more than one directly measured value.

Values reported for congeners within the various congener groups ranged as follows:

Congener Group	Octanol/Water Partition Coefficient
TCDD	5.91 to 8.84
PeCDD	6.2 to 9.69
HxCDD	6.85 to 10.55
HpCDD	8.2 to 11.54
OCDD	7.46 to 8.6
TCDF	5.6 to 6.73
PeCDF	6.19 to 6.92
HxCDF	not available
HpCDF	7.92
OCDF	7.05 to 13.35

The range for the CDDs covers nearly six orders of magnitude, and for the CDFs nearly seven orders of magnitude.

The measured and literature-estimated log K_{ow} values for the PCBs are similar to those reported for the CDDs and CDFs. The values range from 5.62 (measured) for 3,3',4,4'-TeCB to 7.71 (literature-estimate) for 2,3,3',4,4',5,5'-HpCB. The log K_{ow} values increase with an increase in the number of chlorine substituents. The log K_{ow} for the 3,3',4,4'-TeCB was measured by Hawker and Connell (1988) using the generator

column technique against the linear relationship of relative retention time on a nonselective gas chromatograph stationary phase. This was the only directly measured log K_{ow} for the PCBs; therefore, it was considered the most definitive. Log K_{ow} values for the HxCBs were measured by Risby et al. (1990) using a high-performance liquid chromatographic (HPLC) system. The values reported in Tables 2-3 and A-1 are an average of the two techniques because both methods were determined to be equally valid. The values for the HxCBs were ranked 3 because both methods produced similar values. The most definitive values for the other PCBs were either derived values or the most current estimated value.

Partition coefficient values were calculated for those compounds for which no measured data were reported in the literature by averaging the literature values within congener groups, as were done for vapor pressure and water solubility. Literature values for the hexachlorodibenzofurans could not be found; thus, no congener group average could be calculated. Partition coefficients in the ranges of these reported values indicate that the substances tend to adsorb strongly to organic components in the soil and may bioconcentrate in those organisms exposed to the compounds.

2.4.5. Organic Carbon Partition Coefficient

The organic carbon partition coefficient (K_{oc}) is used in several exposure estimations in Volume 3. K_{oc} is used in the estimation of the adsorption partition coefficient, which describes the partitioning of contaminants between suspended sediment and the water column. K_{oc} is also used in estimating the concentration of contaminants in below ground vegetables grown in contaminated soil.

Measured log K_{oc} values could be found for 2,3,7,8-TCDD in five studies. Lodge and Cook (1989) used contaminated sediments from Lake Ontario and distilled water in glass cylinders to measure the log K_{oc} of 2,3,7,8-TCDD. Log K_{oc} values ranged from 7.25 to 7.59. Jackson et al. (1986) used 10 contaminated soil samples in a batch extraction procedure to measure log K_{oc}. The average log K_{oc} of the 10 soils was reported as 7.39. Marple et al. (1986) used two uncontaminated soils spiked by two different methods with 2,3,7,8-TCDD to obtain the log K_{oc} value. The soil was stirred with water in 2-liter flasks. The log K_{oc} values ranged from 5.96 to 6.54 for both soils, with an average value of 6.40 for the red clay soil and 6.02 for the alluvial soil.

Puri et al., (1989) studied log K_{oc} of 2,3,7,8-TCDD with several other co-contaminants such as crankcase oils and surfactants. An average log K_{oc} value of 5.68 was reported for 2,3,7,8-TCDD in the presence of 0.01 percent surfactant. Walters and Guiseppi-Elie (1988) used several soils and water/methanol mixtures in a batch shake testing procedure to determine the log K_{oc} of 2,3,7,8-TCDD. The study resulted in a log K_{oc} value of 6.6.

Four studies for log K_{oc} of 2,3,7,8-TCDD were ranked number 1. The studies by Jackson et al. (1986) and Lodge and Cook (1989) had confirming values of 7.39 and 7.42, respectively. The studies by Walters and Guiseppi-Elie (1988) and Marple et al. (1987) had confirming values of 6.6 and 6.4, respectively. The 6.6 value reported by Walters and Guiseppi-Elie (1988) was chosen by Syracuse Research Corporation (SRC) in the CHEMFATE Database (SRC, 1991) as the most definitive. This value was determined in a mixed solvent system, water and methanol; therefore, it is not considered as appropriate as a pure water equilibration system determined value. The confirming value by Marple et al. (1987), 6.4, was determined in uncontaminated soil and with pure water; therefore, this value is considered the most definitive for this document.

Webster et al. (1986) used a modified generator column technique to measure the organic carbon partition coefficients of three dioxin-like compounds. Three dissolved humic substances were introduced into the carrier stream to measure the interaction between the contaminants and organic matter. The reported average values at 20° C were 5.97 for 1,2,3,7-TCDD, 5.68 for 1,2,3,4,7-PeCDD, and 5.92 for 1,2,3,4,7,8-HxCDD. Only one value was found for the dioxin-like PCBs, 5.7 for 2,3',4,4',5-PeCB (EPRI, 1990). Compounds that have log K_{oc} values in the ranges reported for these chemicals are expected to strongly sorb to particulate matter.

2.4.6. Photo Quantum Yields

Photo quantum yields, which can be used to estimate the rate of photolysis in the environment, have been reported for only nine congeners:

Congener	Photo Quantum Yield	Reference
1,2,3,7-TCDD	5.42×10^{-4}	(Choudhry and Webster, 1989)
1,3,6,8-TCDD	2.17×10^{-3}	(Choudhry and Webster, 1989)
2,3,7,8-TCDD	2.2×10^{-3}	(Dulin et al., 1986)
2,3,7,8-TCDD	3.3×10^{-2}	(Rapaport and Eisenreich, 1984)
1,2,3,4,7-PeCDD	9.78×10^{-5}	(Choudhry and Webster, 1987)
1,2,3,4,7,8-HxCDD	1.10×10^{-4}	(Choudhry and Webster, 1987)
1,2,3,4,6,7,8-HpCDD	1.53×10^{-5}	(Choudhry and Webster, 1987)
OCDD	2.26×10^{-5}	(Choudhry and Webster, 1987)
1,2,4,7,8-PeCDF	1.29×10^{-2}	(Choudhry et al., 1990)
1,2,3,4,7,8-HxCDF	6.96×10^{-4}	(Choudhry et al., 1990)

All quantum yields were measured in a water-acetonitrile solution at 313 nm, except those reported by Rapaport and Eisinreich (1984) which were measured in the vapor phase at 250-360 nm. No values were found for the PCBs.

Homologue group averages were not calculated because photo quantum yields are very sensitive to chlorine position and the solvent system used in the experiments. Different water to acetonitrile volume ratios were used in these experiments.

2.5. PHYSICAL CHEMICAL PROPERTIES - BROMINATED COMPOUNDS

Information on the physical and chemical properties of the polybrominated dioxins and furans is very limited. Dr. G. R. B. Webster, University of Manitoba is expected to will publish measured results for testing with brominated compounds in the near future.

2.6. ENVIRONMENTAL FATE - CHLORINATED COMPOUNDS

2.6.1. Environmental Fate of Chlorinated Dibenzo-p-dioxins (CDDs) and Chlorinated Dibenzofurans (CDFs)

2.6.1.1. Summary

The growing body of literature from laboratory, field, and monitoring studies examining the environmental transformation and environmental distribution of CDDs and CDFs has increased the understanding of the fate of these environmentally ubiquitous compounds. In soil, sediment, the water column, and probably air, CDDs/CDFs are primarily associated with particulate and organic matter because of their high lipophilicity and low water solubility. They exhibit little potential for significant leaching or volatilization once sorbed to particulate matter. The available evidence indicates that CDDs and CDFs, particularly the tetra- and higher chlorinated congeners, are extremely stable compounds under most environmental conditions. The only environmentally significant transformation process for these congeners is believed to be photodegradation of nonsorbed species in the gaseous phase or at the soil or water-air interface. CDDs/CDFs entering the atmosphere are removed either by photodegradation or by dry or wet deposition. Burial in-place or erosion of soil to water bodies appears to be the predominant fate of CDDs/CDFs sorbed to soil. CDDs/CDFs entering the water column primarily undergo sedimentation and burial. The ultimate environmental sink of CDDs/CDFs is believed to be aquatic sediments.

2.6.1.2. Transport Mechanisms

2.6.1.2.1. Transport Mechanisms in Air. Once released into the atmosphere, CDDs and CDFs become widely dispersed throughout the environment by atmospheric transport and deposition. In a recent assessment of the atmospheric transport and deposition of CDDs and CDFs for EPA, Hites and Harless (1991) generated data and analyses that support the contention that background environmental levels and congener profiles of CDDs and CDFs in soils and sediment (i.e., higher rather than lower chlorinated congener patterns

predominate) can be attributed, in large part, to the atmospheric transport and transformation of CDDs and CDFs released from combustion sources.

Hites and Harless (1991) showed that during transport there is partitioning between the vapor and particle-bound phases. The two key parameters controlling the phase in which a particular congener is found are the congener's vapor pressure and the atmospheric temperature. Congeners with higher vapor pressures are found to a greater extent in the vapor phase. A comprehensive evaluation of the partitioning of dioxin-like compounds between vapor and particle phases was performed in Volume III of this three-volume document. Ambient air monitoring studies that examined the partitioning of dioxin-like compounds between vapor and particle phases were summarized in the Volume III evaluation. A theoretical approach developed by Bidleman (1988) was also discussed, and this approach was used to model the vapor/particle (V/P) partitioning for purposes of evaluating the impact of stack emissions. Table 2-4 summarizes the V/P partitioning reported in several ambient air monitoring studies and also the V/P partitioning estimated by the Bidleman (1988) model. The results are presented as V/P ratios (i.e., the ratio of the concentration of a compound in the vapor phase to the concentration of that compound in the particulate phase on a volume-to-volume basis). From the review in Volume III, the following conclusions were made:

- Ambient air sampling methods do give an approximate indication of the V/P ratio that seems to be responsive to changes in temperature and to the degree of chlorination of the CDDs/CDFs. This is in accordance with what would be expected from their individual vapor pressures. The methods present a realistic picture of partitioning under variable ambient conditions. However, the method has certain limitations that currently prevent deriving a true measurement of V/P partitioning in the ambient air. First, the glass fiber filter is designed to capture and retain particulate matter greater than or equal to 0.1 μm diameter. Particles less than this diameter may pass through the filter and be retained in the polyurethane foam vapor trap downstream. If this is the case, the amount of CDDs/CDFs observed to be particle-bound would be underestimated, and the amount observed to be in vapor phase would be overestimated. Second, the relatively high volume of sampled air passing through the system (200 to 400 m^3 of air per 24 hours) may redistribute the more volatile congeners from the filter to the adsorbent trap by a process known as 'blow-off'. Again, this would lead to an overestimate of the fraction in the vapor phase.

Table 2-4. Vapor-to-Particle-Bound Ratio (V/P) for CDDs and CDFs in Ambient Air: Monitoring Results and Modeling Estimates

Homologue Group	CDD/CDF V/P RATIOS[a]	
	Monitoring Studies[b]	Modeling Estimates[c]
TCDD	6.69	1.22
PeCDD	2.22	0.35
HxCDD	0.43	0.04
HpCDD	0.11	0.02
OCDD	0.04	0.01
TCDF	4.88	2.45
PeCDF	1.86	0.56
HxCDF	0.54	0.08
HpCDF	0.12	0.03
OCDF	0.02	0.01

[a] V/P ratio is the ratio of the concentration of CDD/CDF in the gaseous phase (mass per m^3 of air) to the concentration of CDD/CDF in the particulate phase (mass per m^3 of air).

[b] Average of 15 data points from 6 references; "not reported" and "not detected" values were not included in the averages.

[c] Calculated for 2,3,7,8-substituted congeners using procedures in Bidleman (1988). For homologue groups with more than one 2,3,7,8-substituted congener, the V/P ratio listed in the table was calculated by dividing the average of the predicted fractions of congeners in the vapor phase by the average of the predicted fractions of congeners in the particulate phase.

- The theoretical construct relies on current adsorption theory, considers the molecular weight and the degree of halogenation of the congeners, uses the boiling points and vapor pressures of the congeners, and uses the availability of surface area on atmospheric particles for adsorption that correspond to a variety of ambient air shed classifications having variable particulate matter densities. Four air shed classifications are described in Bidleman (1988): "clean continental", "background", "background plus local sources", and "urban". The classification used in Volume III for evaluating impacts in a rural environment is "background plus local sources". It is noted from Table 2-4 that the V/P ratios determined theoretically indicate less compound in the vapor phase (or equivalently, more in the particle phase) than is reported in the monitoring studies. This is consistent with the discussion above suggesting that the ambient air instrumentration could overestimate the vapor fraction because of instrumentation design and performance.

Towara et al. (1993) studied the particle size distribution of atmospheric particle-bound CDD/CDFs. Three 48-hour samples were collected in a rural area of Germany during the summer of 1992. Particles with aerodynamic diameters of less than 1.35 μm (i.e., particles that have relatively long residence times in the atmosphere) accounted for 65, 84, and 82 percent of the total particle mass in the three samples. However, these small particles accounted for 91, 90, and 85 percent of the total mass of CDD/CDFs found in all particle sizes combined.

CDDs and CDFs are removed physically from the atmosphere by wet deposition (i.e., scavenged by precipitation), particle dry deposition (i.e., gravitational settling of particles) and gas-phase dry deposition (i.e., sorption of CDD/CDFs in the vapor phase onto plant surfaces) (Rippen and Wesp, 1993; Welsch-Pausch et al., 1993). Precipitation can be very effective in removing CDDs and CDFs from the atmosphere. Listed in Table 2-5 are the average precipitation scavenging ratios for congener groups reported by Hites and Harless (1991) and Koester and Hites (1992a) for Bloomington, Indiana, and Indianapolis, Indiana, respectively. The scavenging ratio is the ratio of the concentration of a chemical in precipitation (rain in these studies) to the concentration in the atmosphere and is a measure of the effectiveness of rain in removing the chemical. Also listed in Table 2-5 are the percentages of congener groups scavenged as particles in rain rather than as dissolved solutes in rain. Total rain scavenging ratios ranged from 10,000 to 150,000; hepta- and octa- CDDs (i.e., the congeners most strongly associated with particulates) were scavenged most efficiently.

Table 2-5. Rain Scavenging Ratios (W) and Percent Washout Due to Particulates (%P) for CDDs and CDFs in Bloomington and Indianapolis Ambient Air

Congener Group	Bloomington, IN		Indianapolis, IN	
	W	%P	W	%P
TCDD	a	a	a	a
PeCDD	10,000	50	30,000	67
HxCDD	10,000	88	26,000	69
HpCDD	62,000	93	91,000	78
OCDD	90,000	80	150,000	60
TCDF	22,000	21	33,000	24
PeCDF	14,000	54	18,000	35
HxCDF	11,000	77	15,000	74
HpCDF	34,000	88	32,000	79
OCDF	21,000	52	41,000	87
Total CDD/CDF	---	68	---	64

[a] Rarely detected; no calculations performed.

Sources: Hites and Harless (1991); Koester and Hites (1992a).

As part of their studies, Hites and Harless (1991) and Koester and Hites (1992a) also measured dry deposition of CDDs and CDFs and calculated wet and dry deposition fluxes to determine which process dominated CDD/CDF deposition. The calculated wet deposition flux for both cities was similar; 220 ng/m^2-yr for Indianapolis and 210 ng/m^2yr for Bloomington as might be expected based on similar rainfall patterns. However, the dry deposition fluxes differed by a factor of two between the cities (160 ng/m^2-yr for Bloomington and 320 ng/m^2-yr for Indianapolis). Wet deposition was calculated to be the dominant process for Bloomington; whereas, dry deposition was calculated to be the dominant process for Indianapolis. The difference was attributed to the higher total suspended particulate matter in Indianapolis air.

2.6.1.2.2. Transport Mechanisms in Soil. Upon deposition of CDDs/CDFs onto soil or plant surfaces, there can be an initial loss due to photodegradation and/or volatilization. The extent of initial loss due to volatilization and/or photodegradation is uncertain and may be controlled by climatic factors, soil characteristics, and the concentration and physical form of the deposited CDDs/CDFs (i.e., particulate-bound, dissolved in solvent, etc.) (Freeman and Schroy, 1989; Paustenbach et al., 1992). For example, observations from the Seveso incident indicated that when 2,3,7,8-TCDD was deposited on the soil surface, the levels in the surface soil decreased substantially in the first 6 months (DiDomenico et al., 1982). Similarly, Nash and Beall (1980) reported that 12 percent of the 2,3,7,8-TCDD applied to bluegrass turf as a component (7.5 ppm concentration) of an emulsifiable Silvex concentrate volatilized over a period of nine months.

Because of their very low water solubilities and vapor pressures, CDDs/CDFs below the soil surface (i.e., below the top few millimeters) are strongly adsorbed and show little upward or downward vertical migration, particularly in soils with a high organic carbon content (Yanders et al., 1989). Freeman et al. (1987) found no statistically meaningful changes in the concentration profile of 1,2,7,8-TCDD in the top 1 cm of Time Beach Soil over a 16-month period, with the exception of the top 3mm of soil exposed to water and sunlight in which 50 percent reduction in 2,3,7,8-TCDD concentration was observed. In addition, the more chlorinated congeners do not show any significant degree of degradation below the soil surface. Although for several years it was believed that near-surface (i.e., the top 1cm) CDDs/CDFs could volatilize slowly to the surface (Freeman and

Schroy, 1985), recent research has indicated that CDDs/CDFs, particularly the tetra and higher chlorinated congeners, show little or no movement upward or downward in the subsurface unless a carrier such as waste oil or diesel fuel is present to act as a solvent. For example, Palausky et al. (1986) injected 2,3,7,8-TCDD dissolved in various organic solvents into soil columns to determine the extent of vapor phase diffusion; little movement due to volatilization was observed unless the soil was incubated at 40°C.

Paustenbach et al. (1992) reviewed many major published studies on dioxin persistence in soil and concluded that 2,3,7,8-TCDD probably has a half-life of 25 to 100 years in subsurface soil and 9 to 15 years at the soil surface (i.e., the top 0.1 cm). Several major studies reviewed by Paustenbach et al. (1992) and additional recent studies are summarized below. Some of these recent studies have concluded that the binding of dioxin-like compounds to soil approaches irreversibility over time due to the encapsulation of the compounds in soil organic and mineral matter (Puri et al., 1989; Puri et al., 1992).

Orazio et al. (1992) studied the persistence of di- to octa-chlorinated CDDs and CDFs in sandy loam soil held in laboratory columns under water-saturated soil conditions for a period of 15 months. Measurable upward movement was reported only for the dichlorofurans and dioxins. Downward movement was only noticeable for the dichloro- and trichloro-congeners. The mobility of the CDDs and CDFs was not significantly affected by co-contaminants (i.e., pentachlorophenol and creosote components) present at concentrations as high as 6,000 mg/kg. As much as 35 percent loss of the di- and trichloro-congeners due to degradation was observed; no significant degradation of the tetra- through octa-chlorinated congeners was reported (Orazio et al., 1992).

Hagenmaier et al. (1992) collected soil samples around two industrial plants in Germany in 1981, 1987, and 1989 at the same site and from the same depth, using the same sampling method. There was no indication (within the limits of analytical accuracy (+/- 20 percent)) of appreciable loss of CDDs and CDFs by vertical migration, volatilization, or degradation over the 8-year period. Also there were no significant changes in the congener distribution pattern (i.e., tetra- through octa-) over this time period.

Yanders et al. (1989) reported that 12 years after oil containing 2,3,7,8-TCDD was sprayed on unpaved roads at Times Beach, Missouri, no dioxin was discovered deeper than 20 cm. However, these roads were paved about 1 year after the spraying episode, thus

preventing volatilization to the atmosphere. Yanders et al. (1989) excavated this soil and placed the soil in bins located outdoors, subject to the natural conditions of sunlight and precipitation. They reported no appreciable loss nor vertical movement of 2,3,7,8-TCDD from the soil, even in the uppermost sections, during a 4-year study period. Puri et al. (1992) reported no migration or loss of 1,2,3,4-TCDD, 1,2,3,7,8-PeCDD, OCDD, and OCDF from samples of this soil which were examined for 2 years in controlled laboratory column experiments.

Hallett and Kornelson (1992) reported finding 2,3,7,8-TCDD at levels as high as 20 pg/g in the upper 2 inches of soil obtained from areas of cleared forest in New Brunswick, Canada, where the pesticides 2,4-D and 2,4,5-T had been applied in one or more applications 24 to 33 years earlier.

Pereira et al. (1986) reported contamination by CDDs of the sand and gravel aquifer underlying unlined surface impoundments at a wood-treatment facility that had utilized creosote and pentachlorophenol. CDDs migrated both vertically and horizontally in the subsurface. Puri et al. (1992), using soil column experiments in the laboratory, demonstrated that pentachlorophenol and naphthalene and methylnaphthalene (components of creosote) readily transported CDDs/CDFs through soil. Puri et al. (1989) and Kapila et al. (1989) demonstrated that application of waste oil and anionic surfactant solutions to field and laboratory columns of Times Beach soil can move 2,3,7,8-TCDD through soil. Walters and Guiseppe-Elie (1992) showed that methanol/water solutions (1g/L or higher) substantially increase the mobility of 2,3,7,8-TCDD in soils.

Although few studies have evaluated quantitatively the transport of soil-bound CDDs/CDFs, the very low water solubilities and high K_{OC}s of these chemicals indicate that erosion of soil to water bodies appears to be the dominant surface transport mechanism for CDDs/CDFs sorbed to soil (Paustenbach et al., 1992).

2.6.1.2.3. ***Transport Mechanisms in Water.*** Most CDDs/CDFs entering the aquatic environment are associated with particulate matter (e.g., dry deposition of atmospheric particles and eroded soil) and are likely to remain sorbed to the particulate matter once in the aquatic environment. Recent studies have demonstrated that dissolved CDDs/CDFs entering the aquatic environment will, like other lipophilic, low water solubility organic

compounds, partition to suspended solids or dissolved organic matter such as humic substances.

Muir et al. (1992) and Servos et al. (1992) recently reported that 48 hours after the addition of 2,3,7,8-TCDF, 1,3,6,8-TCDD, and OCDD in a sediment slurry to natural lake water/sediment limnocorrals, between 70 and 90 percent had partitioned to suspended particulates. The proportion freely dissolved in water ranged from <2 percent for 2,3,7,8-TCDF and OCDD to 10 to 15 percent for 1,3,6,8-TCDD. The remainder was associated with dissolved organic substances.

Broman et al. (1992) analyzed water collected from nine sampling points in the Baltic Sea selected to be representative of background levels. The concentration of particle-associated (>0.45mm) total CDDs/CDFs varied between 0.170 and 0.390 pg/L with an average concentration of 0.230 pg/L (or 66 percent of total CDDs/CDFs). The total CDD/CDF concentration of the "apparently" dissolved fraction varied between 0.036 and 0.260 pg/L with an average concentration of 0.120 pg/L (or 34 percent of the total). Subsequent calculations estimated that, on average, only 0.070 pg/L of the "apparently" dissolved CDDs/CDFs were truly dissolved.

The dominant transport mechanism for removal of CDDs/CDFs from the water column is believed to be sedimentation and ultimately burial in sediments; sediment resuspension and desorption of CDDs/CDFs will vary on a site-by-site basis. Servos et al. (1992) reported that the 1,3,6,8-TCDD and OCDD added as a sediment slurry to lake limnocorrals rapidly partitioned/settled to surficial sediments where they persisted over the 2 years of the study. The half-lives of 1,3,6,8-TCDD and OCDD in the water column were reported as 2.6 and 4.0 days, respectively. Based on sediment trap and mixed surface layer studies of the Baltic Sea, Broman et al. (1992) report that the mass of CDDs/CDFs in the mixed surface layer at any moment represents about 1 percent of the total flux of CDDs/CDFs to the sediment annually; this implies little recirculation of these compounds within the water column of the Baltic Sea. Broman et al. (1992) also reported that the concentration of CDDs/CDFs in settling solids (i.e., sediment trap collected material) is approximately one order of magnitude greater than the concentration in suspended particulates. They attributed this elevated concentration to the capacity of settling solids to scavenge the dissolved fraction as the solids settle through the water column. Similar

findings have been reported elsewhere (e.g., Baker et al., 1991) for PCBs and PAHs in the Great Lakes.

Even though they possess very low vapor pressures, CDDs/CDFs can volatilize from water. However, volatilization is not expected to be a significant loss mechanism for the tetra- and higher chlorinated CDDs/CDFs from the water column under most non-spill scenarios. Podoll et al. (1986) calculated volatilization half-lives of 15 days and 32 days for 2,3,7,8-TCDD in rivers and ponds/lakes, respectively. Broman et al. (1992) used measured concentrations of CDDs/CDFs in ambient air (gaseous phase) and in Baltic Sea water (truly dissolved concentrations) to calculate the fugacity gradient over the air-water interface. The fugacity ratios obtained indicated a net transport from air to water (ratios between 0.4 and 0.004).

Fish and invertebrates bioaccumulate CDDs/CDFs, although the benthic and pelagic pathways by which the accumulation occurs are not well understood. Organisms have been shown to accumulate CDDs/CDFs when exposed to contaminated sediments and also to bioconcentrate CDDs/CDFs dissolved in water. However, since most of the CDDs/CDFs in the water column and sediment are associated with particulate matter and dissolved organic matter, the accumulation observed in the environment may be primarily food chain-based starting with uptake by benthic organisms (e.g., mussels, chironomids) directly from sediment pore waters and/or by ingestion or filtering of contaminated particles. Those organisms consuming benthic organisms (e.g., crayfish, suckers) would then pass the contaminants up the food chain (Muir et al., 1992).

2.6.1.3. Transformation Processes

2.6.1.3.1. Photodegradation. Photodegradation appears to be the most environmentally significant degradation mechanism for CDDs/CDFs in water, air, and soil. CDDs/CDFs absorb electromagnetic radiation at wavelengths greater than 290 nm (i.e., the lower bound of the sun's radiation reaching the earth's surface) and, therefore, can be expected to be subject to photolysis by sunlight (Koester and Hites, 1992b). The photochemistry of CDDs has been reviewed by Miller and Zepp (1987), Choudry and Webster (1987), and Esposito et al. (1980). This section summarizes the key findings of those reviews and the results of recent environmentally significant studies.

Laboratory studies have demonstrated that CDDs/CDFs undergo photolysis, typically following first order kinetics, in the presence of a suitable hydrogen donor such as oil or an organic solvent. Study results, when extrapolated to environmental conditions, indicate half-lives ranging from hours to days. The major products of photolysis are lower chlorinated CDDs/CDFs. In general, the rate of photolysis increases as the degree of chlorination decreases and, within a congener group, as the degree of ortho substitution decreases.

Most studies performed to date have been in a laboratory setting using laboratory lighting, pure compounds, and solvent solutions or clean solid surfaces as the reaction substrate. Because of the difficulties inherent in controlling experimental variables, few studies have been performed with gaseous-phase CDDs/CDFs or with surfaces or solutions that may more accurately simulate real world matrices. Thus, although photolysis of CDDs/CDFs at environmentally significant rates has been observed in laboratory studies, the results of these studies may not be representative of photolysis rates that occur under actual environmental conditions. The following paragraphs summarize some of the key studies to date regarding photolysis of CDDs/CDFs in the environment and the relevance of their findings.

Photodegradation in Water. Numerous studies have demonstrated that CDDs/CDFs will undergo photolysis following first order kinetics in solution. Photolysis is slow in water but increases dramatically when solvents serving as hydrogen donors are present such as hexane, benzene, methanol, acetonitrile, isooctane, and acetonitrile/water (Dobbs and Grant, 1979; Crosby et al., 1978; Dulin et al., 1986; Choudry and Webster, 1989; Friesen et al., 1990a; Hutzinger, 1973; Buser, 1988; Koester and Hites, 1992; and others). As noted above, the photolytic behavior of CDDs/CDFs in an organic solvent or a water-organic solvent may not accurately reflect the photolytic behavior of these compounds in natural waters. Natural waters have differing quantities and types of suspended particulates and dissolved organic material that could either retard or enhance the photolysis of CDDs/CDFs. For example, Choudry and Webster (1989) reported that photolysis of 1,3,6,8-TCDD was slower in a pond water matrix than was predicted from a laboratory solution. Conversely, Friesen et al. (1990a) and Friesen et al. (1993) reported

that photolysis of PeCDD, HpCDD, TCDF, and PeCDF proceeds much faster in a pond or lake water matrix than was predicted from or measured in a laboratory solution.

Dobbs and Grant (1979) investigated the photolysis of a series of hexa-, hepta-, and octa-CDDs in hexane. Photolysis half-lives ranged from 0.4 days to 2 days. Meta- and para-substituted congeners were degraded more rapidly than ortho-substituted congeners. Dulin et al. (1986) studied the photolysis of 2,3,7,8-TCDD in various solutions under sunlight and artificial light. Using the results obtained in a water:acetonitrile solution (1:1, v/v) under sunlight conditions, Dulin et al. (1986) calculated the half-life of 2,3,7,8-TCDD in surface water in summer at 40 degrees north latitude to be 4.6 days. The quantum yield for photodegradation of 2,3,7,8-TCDD in water was three times greater under artificial light at 313 nm than under sunlight, and the artificial light photolysis quantum yield for hexane, a good hydrogen donor, was 20 times greater than for the water:acetonitrile solution, a poor hydrogen donor.

Podoll et al. (1986) used the Dulin et al. (1986) quantum yield data for the water:acetonitrile solution to calculate seasonal half-life values for dissolved 2,3,7,8-TCDD at 40 degrees north latitude in clear near-surface water. The seasonal values for half-lives were calculated to be 0.9 days in summer, 2.1 days in fall, 4.9 days in winter, and 1.1 days in spring.

Choudry and Webster (1989) studied the photolytic behavior under 313 nm light of a series of CDDs in a water:acetonitrile solution (2:3, v/v). Assuming that the quantum yields observed in these studies are the same as would be observed in natural waters, Choudry and Webster (1989) estimated the mid-summer half-life values at 40 degrees north latitude in clear near-surface water to be as follows: 1,2,3,7-TCDD (1.8 days); 1,3,6,8-TCDD (0.3 days); 1,2,3,4,7-PeCDD (15 days); 1,2,3,4,7,8-HxCDD (6.3 days); 1,2,3,4,6,7,8-HpCDD (47 days); and OCDD (18 days). In addition, the authors also experimentally determined the sunlight photolysis half-life of 1,3,6,8-TCDD in pond water to be 3.5 days (i.e., ten times greater than the half-life predicted by laboratory experiments).

A recent study by Friesen et al. (1990a) examined the photolytic behavior of 1,2,3,4,7-PeCDD and 1,2,3,4,6,7,8-HpCDD in water:acetonitrile (2:3, v/v) and in pond water under sunlight conditions at 50 degrees north latitude. The observed half-lives of

these two compounds in the acetonitrile solution were 12 and 37 days, respectively, and 0.94 and 2.5 days in pond water, respectively.

Crosby et al. (1973) reported that polychlorinated dibenzofurans undergo photolytic dechlorination in the presence of a hydrogen donor, with more highly chlorinated congeners being more stable. In contrast, Hutzinger (1973) and Buser (1976) reported that the more highly chlorinated congeners undergo photodegradation at a rate similar to that of lower chlorinated CDFs. Hutzinger (1973) found that both 2,8-DCDF and OCDF photolyze rapidly in methanol and hexane.

Buser (1988) studied the photolytic decomposition rates of 2,3,7,8-TCDF, 1,2,3,4-TCDF, and 1,2,7,8-TCDF in dilute isooctane solutions under sunlight and artificial laboratory illumination (fluorescent lights). When the solutions were illuminated with sunlight, the estimated half-lives were 0.2 days for a solution containing 3 ng/μl of 2,3,7,8-TCDF, 0.1 days for a solution containing 2 ng/μl of 1,2,3,4-TCDF, and 0.4 days for a solution containing 0.3 ng/μl of 1,2,7,8-TCDF. For the same solutions illuminated with artificial light, the half-lives were greater than 28 days.

Friesen et al. (1993) studied the photodegradation of 2,3,7,8-TCDF and 2,3,4,7,8-PeCDF using water: acetonitrile (2:3, v/v) and lake water. The observed half-lives of the TCDF and PeCDF in the acetonitrile solution were 6.5 and 46 days, respectively, and 1.2 and 0.19 days in lake water, respectively.

Photodegradation in Soil. As discussed in Section 2.6.1.2.2 (Transport Mechanisms in Soil), photodegradation of CDDs/CDFs is limited only to the soil surface. Below the top few millimeters of soil, photodegradation is not a significant process (Puri et al., 1989; Yanders et al., 1989). Substantial research on the environmental persistence of 2,3,7,8-TCDD has been performed as part of the decontamination of the area around the ICMESA chemical plant in Seveso, Italy. That area was contaminated when a trichlorophenol reaction vessel overheated in 1976, blowing out the safety devices and spraying dioxin-contaminated material into the environment. The levels of dioxin in the soil decreased substantially during the first 6 months following the accident, reaching a steady state of 1/5 to 1/11 of the initial levels (DiDomenico et al., 1982). An experiment was conducted at this site to determine the effectiveness of photolysis in decontaminating surface deposits on foliage. Test plots were sprayed with olive oil to act as a hydrogen

donor, and the levels of dioxin on grass were found to be reduced by over 80 percent within 9 days (Crosby, 1981). The 2,3,7,8-TCDD in contaminated soil was also found to be photolabile in sunlight when the soil was suspended in an aqueous solution of a surfactant. The destruction of 8 μg/ml of 2,3,7,8-TCDD in 0.02 M hexadecylpyridinium chloride could be accomplished in 4 hours (Botre et al., 1978).

Buser (1988) studied the photolytic decomposition rates of 2,3,7,8-TCDF, 1,2,3,4-TCDF, and 1,2,7,8-TCDF dried as thin films on quartz vials. When exposed to sunlight, the substances slowly degraded with reported half-lives of 5 days, 4 days, and 1.5 days, respectively.

Koester and Hites (1992b) studied the photodegradation of a series of tetra- through octa-chlorinated CDDs and CDFs on silica gel. In general, the CDFs degraded much more rapidly than the CDDs, and half-lives increased with increasing level of chlorination (1,2,7,8-TCDF excluded). The half-lives for CDDs ranged from 3.7 days for 1,2,3,4-TCDD to 11.2 days for OCDD. The half-lives for CDFs ranged from 0.1 day for 1,2,3,8,9-PeCDF to 0.4 days for OCDF.

Photodegradation in Air. Photolysis of CDDs/CDFs in the atmosphere has not been well-characterized. Based on the data generated to date, however, photolysis appears to be the most significant mechanism for degradation of those CDDs/CDFs present in the atmosphere in the gas phase. For airborne CDDs/CDFs sorbed to particulates, photolysis appears to proceed very slowly, if at all. Because of the low volatility of CDDs/CDFs, few studies have been attempted to measure actual rates of photodegradation of gaseous-phase CDD/CDF, and only recently have studies been undertaken to examine the importance of photolysis to particulate-bound CDDs/CDFs.

Podoll et al. (1986) estimated the photolysis rate of 2,3,7,8-TCDD vapors in the atmosphere. Based on the quantum yield for photolysis in hexane, the half-life in summer sunlight at 40 degrees north latitude was calculated to be 1 hour, but Podoll et al. (1986) stated this estimate is an upper limit.

Mill et al. (1987) reported preliminary photolysis experiments with vapor phase 2,3,7,8-TCDD. The half-life for vapor phase 2,3,7,8-TCDD in simulated sun was several hours. The photolysis of 2,3,7,8-TCDD sorbed onto small diameter fly ash particulates suspended in air was also measured. The results indicated that fly ash appears to confer

photostability on 2,3,7,8-TCDD. There was little (8 percent) to no loss observed on the two fly ash samples after 40 hours of illumination.

Orth et al. (1989) conducted photolysis experiments with vapor-phase 2,3,7,8-TCDD under illumination with a light source and filters to achieve radiation in the UV region from 250 nm to 340 nm. Carrier gases included air, helium, and an isobutane/helium mixture. The rate constants in helium and air were very similar, 5.4 x 10^{-3} sec^{-1} and 5.9 x 10^{-3} sec^{-1}, which corresponds to a quantum yield in air of 0.033 $\pm$ 0.046. No products could be observed in the mass spectrometer, so Orth et al. (1989) postulated that the product might be sorbing to the surface of the photolysis cell and being lost from potential analysis. Further studies were suggested to study product sorption to surfaces and to determine any wave length dependence of the photoinduced loss across the absorption band studied.

Koester and Hites (1992b) recently studied the photodegradation of CDDs/CDFs naturally adsorbed to five fly ashes (one from a hospital incinerator, two from municipal incinerators, and two from coal-fired power plants). Although they found that CDDs/CDFs underwent photolysis in solution and when spiked onto silica gel, no significant degradation was observed in 11 photodegradation experiments performed for periods ranging from 2 to 6 days. Three additional experiments were performed to determine what factors may have been inhibiting photolysis. From the results of these additional experiments, Koester and Hites (1992b) concluded that: 1) the absence of photodegradation was not due to the absence of a hydrogen-donor organic substance; 2) other molecules or the ash, as determined by a photolysis experiment with an ash extract, inhibit photodegradation either by absorbing light and dissipating energy or by quenching the excited states of the CDDs/CDFs; and 3) the surface of the ash itself may hinder photolysis by shielding the CDDs/CDFs from light.

2.6.1.3.2. Oxidation. Stehl (1973) has suggested that 2,3,7,8-TCDD is probably stable to oxidation in the ambient environment. The reaction rates of hydroxyl (OH) radicals with CDDs and CDFs have not been measured because, in part, the low vapor pressures of these compounds make direct measurements very difficult with currently available techniques. However, Podall et al. (1986) estimated the half-life of 2,3,7,8-TCDD vapor

via OH oxidation in the atmosphere to be 8.3 days. Atkinson (1987) estimated the atmospheric lifetime of about 3 days for 2,3,7,8-TCDD due to the OH radical reaction.

2.6.1.3.3. Hydrolysis. There is no available evidence indicating that hydrolysis would be an operative environmental process for degradation of CDDs or CDFs (Leifer et al., 1993; Miller and Zepp, 1987).

2.6.1.3.4. Biotransformation and Biodegradation. Investigations on the biodegradability of CDDs and CDFs have focused on the microbial degradation of 2,3,7,8-TCDD. Arthur and Frea (1989) provided a comprehensive review of studies conducted during the 1970s and 1980s. Arthur and Frea (1989) concluded that 2,3,7,8-TCDD is recalcitrant to microbial degradation. Several major studies conducted during this period are discussed below.

Matsumura and Benezet (1973) tested approximately 100 strains of micro-organisms that were shown previously to degrade persistent pesticides; only five strains showed any ability to degrade 2,3,7,8-TCDD, based on autoradiographs of thin-layer chromatograms. Although it is possible that the less chlorinated dioxins are more susceptible to biodegradation, microbial action on 2,3,7,8-TCDD is very slow under optimum conditions (Hutter and Philippi, 1982). Long-term incubations of radiolabeled 2,3,7,8-TCDD yielded no radioactivity in carbon dioxide traps after 1 year, and analyses of the cultures showed that at most, 1 to 2 percent of a potential metabolite (assumed to be a hydroxylated derivative of 2,3,7,8-TCDD) could be detected. Camoni et al. (1982) added organic compost to contaminated soil from the Seveso area to enrich the soil and enhance the 2,3,7,8-TCDD biodegradation rate; however, the soil amendment had no clear effect on degradation. Quensen and Matsumura (1983) reported that low concentrations (5 ppb) of radiolabelled 2,3,7,8-TCDD were metabolized by pure cultures of *Nocardiopsis* spp. and *Bacillus megaterium* that had been isolated from farm soil. The extent of metabolism after 1 week incubation was strongly dependent on the carrier solvent used to dissolve and introduce the 2,3,7,8-TCDD to the culture medium. The solvent ethyl acetate gave the best results; 52 percent of $_{14}C$ was recovered as 2,3,7,8-TCDD out of a total of 77 percent $_{14}C$ recovered. However, incubation of 2,3,7,8-TCDD in farm soil, garden soil, and forest soil resulted in little, if any, metabolism of 2,3,7,8-TCDD.

Bumpus et al. (1985) tested the white rot fungus, *Phanerochaete chrysosporium*, which secretes a unique H_2O_2-dependent extracellular lignin-degrading enzyme system capable of generating carbon-centered free radicals. Lignin is resistant to attack by all micro-organisms except some species of fungi and a relatively small number of bacteria species. Radiolabeled 2,3,7,8-TCDD was oxidized to labeled CO_2 by nitrogen-deficient, ligninolytic cultures of *P. chrysosporium;* since the label was restricted to the ring, it was concluded that the strain was able to degrade halogenated aromatic rings. In 10 ml cultures containing 1,250 pmol of substrate, 27.9 pmol of 2,3,7,8-TCDD were converted to labeled-CO_2 during the 30-day incubation period; thus, only about 2 percent of the starting material were converted.

Hoffman et al. (1992) demonstrated that the fungi, *Fusarium redolens*, could degrade 3-chlorodibenzofuran and, to a lesser degree, mono- and di-CDDs. Hoffman et al. (1992) also identified 14 other strains of fungi that demonstrated the capability to degrade dibenzofuran (nonchlorinated). The strains are members of the following genera: *Mucor, Chaetomium, Phoma, Fusarium, Paecilomyces, Papulaspora, Inonotus, Lentinus, Phanerochaete, Polyporus, Pycnoporus, Schizophyllum*, and *Trametes*.

2.6.2. Environmental Fate of Coplanar PCBs

2.6.2.1. Summary

Little specific information exists on the environmental transport and fate of the 11 coplanar PCBs. However, the available information on the physical/chemical properties of coplanar PCBs coupled with the body of information available on the widespread occurrence and persistence of PCBs in the environment indicates that these coplanar PCBs are likely to be associated primarily with soils and sediments, and to be thermally and chemically stable. Soil erosion and sediment transport in waterbodies and volatilization from the surfaces of soils/water bodies with subsequent atmospheric transport and deposition are believed to be the dominant current transport mechanisms responsible for the widespread environmental occurrence of PCBs. Photodegradation to less chlorinated congeners followed by slow anaerobic and/or aerobic biodegradation is believed to be the principal path for destruction of PCBs.

2.6.2.2. Transport Mechanisms

Based on their low vapor pressures, low water solubilities, and high K_{oc} values, coplanar PCBs are expected primarily to be associated with soils, sediments, and particulates; however, due to the stability and persistence of coplanar PCBs via other transformation and transport pathways, volatilization is likely to be a significant transport mechanism from a global perspective. It should be noted that although coplanar PCBs have low vapor pressures and water solubilities, the Henry's Law constants for the similarly substituted CDDs and CDFs are expected to be one to two orders of magnitude lower. Therefore, it can be expected that volatilization, as well as desorption of PCBs from particulate matter into air and water, is likely to be more significant transport mechanisms for PCBs than for CDDs and CDFs.

For example, Murray and Andren (1992) studied the precipitation scavenging of PCBs in the Great Lakes region. They reported that atmospheric PCBs are largely in the gas phase (typically >90 percent) rather than bound to particulates. Similarly, the results of their study support the hypothesis that precipitation provides episodic inputs of PCBs to the Great Lakes, which are volatilizing the PCBs back to the atmosphere for much of the year, particularly during the summer (Baker and Eisenreich, 1990).

2.6.2.3. Transformation Processes

2.6.2.3.1. Photodegradation. Based on the data available in 1983, Leifer et al. (1983) concluded that all PCBs, especially the more highly chlorinated congeners and those that contain two or more chlorines in the ortho position, photodechlorinate. In general, as the chlorine content increases, the photolysis rate increases. The products of photolysis are predominantly lower chlorinated PCBs.

More recently, Lepine et al. (1992) exposed dilute solutions (4ppm) of Aroclor 1254 in cyclohexane to sunlight for 55 days in December and January. Isomer-specific analysis indicated that the amounts of many higher chlorinated congeners decreased while those of some lower chlorinated congeners increased. These results are consistent with the studies reviewed in Leifer et al. (1983) that indicated photodegradation of PCBs proceeds through successive dechlorination of the biphenyl molecule. The results for the coplanar PCBs indicated a 43.5 percent decrease in the amount of 2,3,4,4',5-PeCB, a 73.5 percent

decrease in the amount of 2,3,3',4,4',5-HxCB, and a 24.4 percent decrease in the amount of 2,3,3',4,4',5'-HxCB. However, 3,3',4,4'-TeCB and 3,3',4,4',5-PeCB, which were not detected in unirradiated Aroclor 1254, represented 2.5 percent and 0.43 percent, respectively, of the irradiated mixture. The authors postulated that formation of these two congeners probably occurred, at least in part, from dechlorination at the ortho position of their mono-ortho-substituted precursors, considering the greater reactivity of PCB ortho chlorines toward photodechlorination.

2.6.2.3.2. Oxidation. Reaction of PCBs with common environmental oxidants such as hydroperoxy radicals (HO_2) and ozone (O_3) has not been reported and are probably not very important because only very strong oxidant species can react with PCBs (Sedlak and Andren, 1991). However, reaction of gas-phase PCBs in the atmosphere and dissolved PCBs in certain surface waters with hydroxyl radicals (OH) (one of the strongest environmental oxidants known) may be an important degradation mechanism.

Atkinson (1987) and Leifer (1983), using assumed steady-state atmospheric OH concentrations and measured oxidation rate constants for biphenyl and monochlorobiphenyl, estimated atmospheric decay rates and half-lives for gaseous-phase PCBs. Atmospheric transformation was estimated to proceed most rapidly for those PCB congeners containing either a small number of chlorines or those containing all or most of the chlorines on one ring. The predicted half-lives for the congener groups containing the 11 coplanar PCBs are as follows:

Congener Group	Half-Life in Air (days)
TeCBs	11 to 20
PeCBs	12 to 31
HxCBs	32 to 62
HpCBs	94+

Sedlak and Andren (1991) demonstrated in laboratory studies that OH radicals, generated with Fenton's reagent, rapidly oxidized PCBs (i.e., 2-mono-PCB and the DiCBs through PeCBs present in Aroclor 1242) in aqueous solutions. The results indicated that the reaction occurs via addition of a hydroxyl group to one nonhalogenated site; reaction rates are inversely related to the degree of chlorination of the biphenyl. The results also indicated that meta and para sites are more reactive than ortho sites due to stearic

hindrance effects. Based upon their kinetic measurements and reported steady-state aqueous system OH concentrations or estimates of OH radical production rates, Sedlak and Andren (1991) estimated environmental half-lives for dissolved PCBs (mono-through octa-PCB) in several water systems as listed below.

Water System	Half-Life in Water (days)
Fresh surface water	4 to 11
Marine surface water	1,000 to 10,000
Cloud water	0.1 to 10

Estimates for dissolved PCBs in marine surface water are in excess of 1,000 days due to the very low concentration of OH radicals in these waters (10^{-18}M or about two orders of magnitude lower than in freshwater systems).

The results of studies to date indicate that, in the atmosphere, OH oxidation of gas-phase PCBs and PCBs dissolved in cloud water may be important, although not very fast, degradation mechanisms for PCBs from a global perspective. However, additional measurements of gas-phase oxidation rates, the ratio of dissolved to sorbed PCBs in cloud water, and OH production and loss rates in cloudwater may provide information that will enable an evaluation of the importance of this mechanism to other degradation mechanisms (Sedlack and Andren, 1991).

2.6.2.3.3. Hydrolysis. PCBs are unlikely to be affected by hydrolysis under environmental conditions because the attachment of chlorines directly to the aromatic ring in PCBs confers hydrolytic stability. Specifically, S_N1 and S_N2 reactions do not take place readily at sp2 hybridized carbons (U.S. EPA, 1988; Leifer et al., 1983).

2.6.2.3.4. Biotransformation and Biodegradation. Leifer et al. (1983) and Brown and Wagner (1990) summarized the available information on the aerobic degradation of PCBs by micro-organisms. Laboratory studies have revealed that there are more than two dozen strains of aerobic, terrestrial micro-organisms widely distributed in the environment that are capable of degrading most PCB congeners with five or fewer chlorines. In general, the rate of aerobic biodegradation decreases with increasing chlorination. For example, the half-lives for biodegradation of tetra-PCBs in fresh surface water and soil are 7 to 60+ days and 12 to 30 days, respectively. For penta-PCBs and higher chlorinated PCBs, the

half-lives in fresh surface water and soil are likely to exceed 1 year. PCBs with all or most chlorines on one ring and PCBs with fewer than two chlorines in the ortho position tend to degrade more rapidly.

Until recent years, little investigation focused on anaerobic microbial dechlorination or degradation of PCBs even though most PCBs eventually accumulate in anaerobic sediments (Risatti, 1992). Environmental dechlorination of PCBs via losses of meta and para chlorines has been reported in field studies for freshwater, estuarine, and marine sediments including those from the Acushnet Estuary, the Hudson River, the Sheboygan River, and Waukegan Harbor (Van Dort and Bedard, 1991). The altered PCB congener distribution patterns found in these sediments (i.e., different patterns with increasing depth or distance from known sources of PCBs) have been interpreted as evidence that bacteria may dechlorinate PCBs in anaerobic sediment.

Results of laboratory studies have also been reported recently. Chen et al. (1988) found that "PCB-degrading" bacteria from the Hudson River could significantly degrade the mono-, di-, and tri-PCB components of a 20 ppm Aroclor 1221 solution within 105 days. These congeners make up 95 percent of Aroclor 1221. No degradation of higher chlorinated congeners (present at 30 ppm or less) was observed, and a separate 40-day experiment with tetra-PCB also showed no degradation.

VanDort and Bedard (1991) reported the first experimental demonstration of biologically-mediated ortho dechlorination of a PCB and stoichiometric conversion of that PCB congener (2,3,5,6-TeCB) to less-chlorinated forms. In that study, 2,3,5,6-TeCB was incubated under anaerobic conditions with unacclimated methanogenic pond sediment for 37 weeks with reported dechlorination to 2,5-DCB (21%), 2,6-DCB (63%), and 2,3,6-TrCB (16%).

Risatti (1992) examined the degradation of PCBs at varying concentrations (10,000 ppm, 1,500 ppm, and 500 ppm) in the laboratory with "PCB-degrading" bacteria from Waukegan Harbor. After 9 months of incubation at 22°C, the 500 ppm and 1,500 ppm samples showed no change in PCB congener distributions or concentrations, thus indicating a lack of degradation. Significant degradation was observed in the 10,000 ppm sediment with at least 20 congeners ranging from TrCBs to PeCBs showing decreases.

Quensen et al (1988) also demonstrated that micro-organisms from PCB-contaminated sediments (Hudson River) dechlorinated most PCBs in Aroclor 1242 under

anaerobic laboratory conditions. Aroclor 1242 contains predominantly tri- and tetra-PCBs. Three concentrations of the Aroclor corresponding to 14, 140, and 700 ppm on a sediment dry-weight basis were used. Dechlorination was most extensive at the 700 ppm test concentration; 53 percent of the total chlorine were removed in 16 weeks, and the proportion of TeCBs through HxCBs decreased from 42 to 12 percent. Much less degradation was observed in the 140 ppm sediment, and no observable degradation was found in the 14 ppm sediment. These results and those of Risatti (1992) suggest that the organism(s) responsible for this dechlorination may require relatively high levels of PCB as a terminal electron acceptor to maintain a growing population.

Quensen et al. (1990) reported that dechlorination of Aroclor 1242, 1254, and 1260 by micro-organisms from PCB-contaminated sediments in the Hudson River and Silver Lake occurred primarily at the meta and para positions; ortho-substituted mono- and di-PCBs increased in concentration. This latter finding is significant because removal of meta and para chlorines from the coplanar PCBs should reduce their toxicity and form less chlorinated congeners that are more amenable to aerobic biodegradation.

2.7. ENVIRONMENTAL FATE - BROMINATED COMPOUNDS

2.7.1. Summary

Although there are no available published studies documenting measured fate rate constants, relatively few studies with measured physical/chemical property data, and few relevant environmental monitoring studies, it is possible to estimate the environmental transport and transformation processes for major BDDs, BDFs, and PBBs using structure activity and property estimation methods. Mill (1989) performed such an assessment and much of what is reported in this section is a summary of that review paper. Also useful are the studies undertaken by Jacobs et al. (1976, 1978) to examine the distribution and fate of PBBs in the environment following the accidental contamination of livestock feed in Michigan in 1973 with the brominated flame retardant, FireMaster BPG. FireMaster BPG (a.k.a., PBB) was found by Jacobs et al. (1976) to be comprised of 2,2',4,4',5,5'-hexabromobiphenyl as the major component, two isomers of pentabromobiphenyl, three additional isomers of hexabromobiphenyl, and two isomers of heptabromobiphenyl.

Mill (1989) concluded that the estimated physical/chemical properties of these compounds indicate they will behave in a similar fashion to their chlorinated analogues. In general, these chemicals are expected to be stable under normal environmental conditions, relatively immobile in the environment, and primarily associated with particulate and organic materials. The only environmentally significant path for destruction is photodegradation. If discharged to the atmosphere, any vapor-phase compounds will probably be rapidly photolyzed. The higher brominated congeners, as their chlorinated counterparts, may be present primarily in a particle-bound rather than gaseous phase. If so, they likely will be more resistant to photolysis and become more widely dispersed in the environment.

Upon deposition onto surfaces, there can be an initial loss due to photodegradation and/or volatilization. Once sorbed onto soils or sediments, however, they are expected to be strongly sorbed with erosion and aquatic transport of sediment the dominant physical transport mechanism. If discharged to water, they are expected to preferentially sorb to solids. Volatilization may also be a significant transport mechanism for nonsorbed chemicals even though they have negligible estimate vapor pressures.

2.7.2. Transport Mechanisms

Little information exists on the environmental transport of BDDs, BDFs, and PBBs. However, the available information on the physical/chemical properties of these compounds and their chlorinated analogs coupled with the body of information available on the widespread occurrence and persistence of the chlorinated analogs in the environment indicates that these compounds are likely to be strongly sorbed by soils, sediments, and other particulate material, and to be resistant to leaching and volatilization.

Jacobs et al. (1978) reported that less than 0.2 percent of 2,2',4,4',5,5'-hexa-PBB (14μg PBB/g of soil) and 2,2',3,4,4',5,5'-hepta-PBB (7μg PBB/g of soil) volatilized from soil incubated for 1 year at 28°C.

2.7.3. Transformation Processes

2.7.3.1. Photodegradation. Photolysis in the atmosphere appears to be a major potential pathway for loss of BDDs and BDFs based on recent studies by Buser. Buser (1988)

studied the photolytic decomposition rates of the following compounds in dilute isooctane solutions and as solid phases on quartz surfaces under sunlight and artificial laboratory illumination: 1,2,3,4-TBDD; 2,3,7,8-TBDD; 2,3,7,8-TBDF; and mono- and dibrominated 2,3,7,8-TCDD and 2,3,7,8-TCDF. Under natural sunlight, estimated half-lives were very short, on the order of minutes. Solid-phase photolysis was significantly slower, in the range of 7 to 35 hours. The major photolytic pathway was reductive dehalogenation with the formation of lower halogenated or unsubstituted dibenzo-p-dioxins and dibenzofurans. The bromo-chlorodibenzofurans degraded faster than either the brominated or chlorinated congeners. The major pathway of photolysis was debromination to form a chlorinated dibenzofuran.

Mill (1989) used the results obtained by Buser (1988) together with assumptions to overcome the lack of quantum yield data from Buser (1988) to estimate the photolysis half-lives of the three brominated-only compounds tested by Buser (1988). Mill (1989) estimated the following half-lives in water (top 1 meter) and for vapor in air (first kilometer above surface) for clear-sky conditions in mid-summer at 40 degrees north latitude:

Compound	Half-Life in Water (hrs)	Half-Life in Air (min)
1,2,3,4-TBDD	7	<1
2,3,7,8-TBDD	2	0.3
2,3,7,8-TBDF	1.7	0.2

Lutes et al. (1992a, 1992b) studied the short-term photochemistry of tetra- and penta-BDDs and BDFs sorbed onto airborne soot particles in 25 m^3 outdoor Teflon film chambers. The emissions from controlled burning of polyurethane foam containing polybrominated diphenyl ether flame retardants served as the source of the BDDs and BDFs. Initial experiments demonstrated that more than 95 percent of the BDDs/BDFs were associated with airborne particulate material; less than 5 percent were in the vapor phase. Particulate phase concentrations of tetra- and penta-CDDs/CDFs were monitored for 3 to 6 hours after introduction of the emissions from the foam burn to the chamber under winter and spring temperatures and sunlight regimes. No significant reduction in concentration was observed. The authors conclude that if photolytic degradation was occurring, then the half-lives are much greater than 3 to 6 hours. Thus, as has been observed with

CDDs/CDFs and with solid phase experiments by Buser (1988) on BDDs/BDFs, particulate bound BDDs/BDFs are much less susceptible to photolysis than are gaseous-phase BDDs/BDFs.

2.7.3.2. Oxidation

No reaction rate data for OH radicals with gaseous-phase BDDs, BDFs, and PBBs could be located. The low vapor pressures of these compounds make direct measurements very difficult with the current techniques. However, Mill (1989), using a structure activity relationship developed by Atkinson (1987), has estimated the half-lives of OH oxidation for the tetra- through octa- BDDs and BDFs. The estimated half-lives listed below indicate that OH oxidation is probably too slow to compete with photolysis.

No. of Br	PBDD Half-Life in Air (hrs)	PBDF Half-Life in Air (hrs)
4	50	420
5	50	430
6	100	960
7	200	1900
8	770	3800

2.7.3.3. Hydrolysis

There is no available evidence indicating that hydrolysis would be a significant degradation process for these compounds.

2.7.3.4. Biotransformation and Biodegradation

Although there are no data available concerning the biodegradability of the brominated analogs of CDDs and CDFs, it is expected that these brominated analogs, especially the more halogenated congeners, will be recalcitrant to biodegradation. The limited data available on PBBs (discussed below) indicates recalcitrance.

Jacobs et al. (1976) reported that PBBs are extremely persistent based on the results of aerobic and anaerobic soil incubation studies for 24 weeks with the flame retardant, PBB. Only one major PBB component, a pentabromobiphenyl isomer, showed any significant disappearance; however, Jacobs et al. (1976) were not certain whether the disappearance was due to microbial degradation, to poor soil extraction efficiency, or

sorption onto glassware. Jacobs et al. (1976) also detected components of PBB in soils from a field that had received manure from a PBB-contaminated dairy herd 10 months earlier (quantitative changes in PBB were not possible because no earlier soil samples had been obtained). Additional soil studies by Jacobs et al. (1978) found no degradation of 2,2',4,4',5,5'-hexa-PBB (14μg/25g soil) or 2,2',3,4,4',5,5'-hepta-PBB (7μg/25g soil) after incubation at 28°C for 1 year.

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3. SOURCES

3.1. OVERVIEW OF SOURCES

The purpose of this chapter is twofold: (1) to identify sources that release dioxin-like compounds into the environment and (2) to derive national estimates for releases from these sources in the United States. The dioxin-like compounds have been found in all media and all parts of the world. This ubiquitous nature of these compounds suggests that multiple sources exist and that long range transport can occur. An unresolved issue is how the relative impacts from local vs. distant sources compare at a particular location. Presumably, in industrial areas, local sources will dominate, and in rural areas, distant sources will dominate. However, site specific considerations such as stack height, wind patterns, magnitude of local sources, etc. could influence these comparisons.

The chlorinated and brominated dioxins and furans have never been intentionally produced other than on a laboratory-scale basis for use in chemical analyses. Rather, they are generated as byproducts from various combustion and chemical processes. PCBs were produced in relatively large quantities for use in such commercial products as dielectrics, hydraulic fluids, plastics, and paints. They are no longer produced in industrialized countries, but continue to be released to the environment through the use and disposal of these products.

Dioxin-like compounds are released to the environment in a variety of ways and in varying quantities depending upon the source. For example,

- Releases to the air occur primarily from combustors and appear to have the most direct influence on human exposure. As discussed in Chapter 4, atmospheric deposition and subsequent accumulation through the food chain appears to be the major pathway of human exposure to dioxin-like compounds.

- Solid residues such as combustor ash, still bottoms, etc. can contain high levels of CDD/CDFs and can collectively contain more of these compounds than are found in air or water discharges. However, these solid residues are not generally released to

the environment in an uncontrolled manner. Rather, they are usually disposed at secure landfills and any leaching to ground water is minimal due to their very low water solubility.

- Water discharges from paper mills, sewage treatment plants, and possibly other industries can contain low levels of CDD/CDFs. These releases can bioaccumulate via the aquatic food chain and ultimately lead to human exposure via fish ingestion.

The major identified sources of environmental release have been grouped into four major types for the purposes of this report:

- Industrial/Municipal Processes: Dioxin-like compounds can be formed through the chlorination of naturally occurring phenolic compounds such as those present in wood pulp. The formation of CDDs and CDFs resulting from the use of chlorine bleaching processes in the manufacture of bleached pulp and paper has resulted in the presence of CDDs and CDFs in paper products as well as in liquid and solid wastes from this industry. Municipal sewage sludge has been found to frequently contain CDDs and CDFs. Influents from industrial facilities, stormwater runoff, microbial metabolism of chlorophenols, and domestic household wastewater have been identified by various researchers as the sources(s) of the CDDs/CDFs.

- Chemical Manufacturing/Processing Sources: Dioxin-like compounds can be formed as by-products from the manufacture of chlorine and such chlorinated compounds as chlorinated phenols, PCBs, phenoxy herbicides, chlorinated benzenes, chlorinated aliphatic compounds, chlorinated catalysts, and halogenated diphenyl ethers. Although the manufacture of many chlorinated phenolic intermediates and products, as well as PCBs, was terminated in the late 1970s in the United States, continued, limited use and disposal of these compounds can result in releases of CDDs, CDFs, and PCBs to the environment. High levels of CDFs have been found in sludge from graphite electrodes used in chloralkali process to manufacture chlorine.

- Combustion and Incineration Sources: Dioxin-like compounds can be generated and released to the environment from various combustion processes when chlorine donor compounds are present. These sources can include incineration of wastes such as municipal solid waste, sewage sludge, hospital, and hazardous wastes; metallurgical processes such as high temperature steel production, smelting operations, and scrap metal recovery furnaces; and the burning of coal, wood, petroleum products, and used tires for power/energy generation.

- Reservoir Sources: The persistent and hydrophobic nature of these compounds causes them to accumulate in soils, sediments, and organic matter and to persist in waste disposal sites. The dioxin-like compounds in these "reservoirs" can be redistributed by various processes such as dust or sediment resuspension resulting in the potential for exposure. Releases from these "reservoirs" are not original sources in a global sense, but can be on a local scale. For example, past air emissions causing deposition onto a watershed with subsequent erosion may have resulted in accumulation in downstream sediments. Future sediment dredging operations could result in short-term significant resuspension of dioxins that had accumulated over a much longer period of time. Similarly, leaf composting operations could lead to releases of the dioxins that had, over the course of a growing season, deposited on or been sorbed to the leaves of deciduous trees in an area. Such leaf reservoirs could also be resuspended during forest fires.

As awareness of these possible sources has grown in recent years, a number of changes have occurred that should reduce the release rates (Rappe, 1992a). For example, releases of dioxin-like compounds have been reduced due to the switch to unleaded automobile fuels (and associated use of catalytic converters and reduction in halogenated scavenger fuel additives), process changes at pulp and paper mills, new emission standards and upgraded emission controls for incinerators, and reductions in the manufacture of chlorinated phenolic intermediates and products.

Some investigators have raised the possibility that major sources exist that have not yet been identified. This suggestion is acknowledged to be quite speculative, but is important to consider. Three studies addressing this issue are summarized below.

Travis and Hattemer-Frey (1991) used the Fugacity Food Chain (FFC) model to predict the contribution of municipal solid waste incinerators, motor vehicles, hospital waste incinerators, residential wood burning, and pulp and paper mill effluents, to the U.S. total environmental input of 2,3,7,8-TCDD. It was estimated that the total input from all five sources combined accounted for only 11 percent of the total 2,3,7,8-TCDD found in the different media in the United States. The authors concluded that this low value indicated: (1) the source term used in the FFC modeling exercise for 2,3,7,8-TCDD may have been too high; (2) some unidentified major source(s) of 2,3,7,8-TCDD exist; or (3) multiple environmental sources of 2,3,7,8-TCDD with no one source dominating the total input.

Rappe (1991) found discrepancies between estimated emissions from known sources of CDDs and CDFs into the Swedish environment and calculated aerial deposition rates. The total emissions in Sweden were estimated by Rappe (1991) as 100 to 250 g TEQ/yr. The deposition rates used by Rappe (1991) were derived from a study by Marklund (1990) who made measurements in rural areas of Sweden and found an average deposition rate of 5 ng of TEQ/m^2 - yr. [Later measurements by Andersson et al. (1992) indicate that deposition in this area has been reduced to about 1 ng of TEQ/m^2-yr due to emissions reductions.] Rappe (1991) multiplied the deposition rate of 5 ng TEQ/m^2-yr by the total land area of Sweden, yielding a total annual deposition for Sweden of 2,250 g of TEQ/yr, which appears to be 10 to 20 times higher (or 2 to 4 times higher using the deposition rate of Andersson et al. [1992]) than the total emissions from sources originating in Sweden. Possible explanations for this discrepancy are (1) uncertainty in the emission estimates, (2) uncertainty in the deposition estimates, (3) long-range transport of dioxin-like compounds from sources outside of Sweden, or 4) existence of unidentified sources. In an earlier publication, Rappe et al. (1987) compared congener patterns found in human and aquatic life tissue samples with the congener patterns found in various known emission sources and contaminated products. A poor correlation was observed

between the congener patterns found in human and environmental samples and the respective potential sources. Rappe et al. (1987) speculated that the observed pattern in human and environmental samples could be the result of a combination of sources, coupled with environmental and biological degradation of the released congeners.

Harrad et al. (1992a; 1992b) have made similar estimates for the United Kingdom. They estimate that the average annual deposition from the atmosphere to the land surface in the United Kingdom is 250 kg of CDD/CDF (on a total mass basis, not TEQ), compared to about 29.1 kg/yr emitted from known sources. As with the other two studies, these discrepancies could be the result of inaccuracies in emission/deposition estimates, long-range transport from outside the country, or unidentified sources. The authors speculated that much of the discrepancy may be accounted for by secondary or "reservoir" sources (i.e. the remobilization and subsequent redeposition of CDD/CDFs already in the environment).

Table 3-1 presents CDD and CDF source-specific air emission estimates reported for West Germany (Fiedler and Hutzinger, 1992), Austria (Riss and Aichinger, 1993), the United Kingdom (ECETOC, 1992), the Netherlands (Koning et al., 1993), Switzerland (Schatowitz et al., 1993), and the United States (based on estimates generated in this document). The emission estimates for West Germany and Switzerland suggest that municipal waste incinerators and metal smelters/refiners are the largest sources of air emissions. In Austria, domestic combustion of wood is believed to be the largest source followed by emissions from the metallurgical industry. In the United Kingdom, municipal waste incinerators and coal combustion are estimated to be the major sources. Municipal waste incinerators are also estimated to be the largest source in the Netherlands. Rappe (1992a) and Lexen et al. (1992) have identified emissions from ferrous and nonferrous metals smelting and refining facilities as potentially the largest current source in Sweden. Rappe (1992a) reported that changes in various industrial practices have led to reductions in dioxin emissions in Sweden from 400 - 600 g of TEQ/yr in 1985 to 100 - 200 g TEQ/yr in 1991.

Similar nationwide emission estimates for the United States have not previously been compiled. This task has been attempted in this document, and the results are

presented in Table 3-1 (air emissions only) and in Table 3-2. Table 3-2 lists emission estimates for the major known or suspected sources that could have releases of dioxin-like compounds to the environment. For each source listed in Table 3-2, estimated emissions to air, water, land, and product are listed where appropriate and where data are adequate to enable an estimate to be made. The term "product" in Table 3-2 is defined to include substances or articles (e.g., paper pulp or sewage sludge that is distributed/marketed commercially) that are known to contain dioxin-like compounds and whose subsequent use may result in releases to the environment. Figure 3-1 is a chart that visually displays the range of emission estimates to air that are reported in Table 3-2.

In order to make each source emission estimate, information was required concerning both the "emission factor" term for the source (e.g., grams TEQ per kg of material processed) and the "production" term for the source (e.g., kg of material processed annually in the United States). Because the quantity and quality of the available information for both terms for each emission source varies considerably, a confidence rating scheme was developed. This scheme is based on a consideration of the following factors:

Basis of Estimate - The basis for the emission estimate varied widely from expert judgement to detailed studies. The best studies involved direct emission measurements at multiple facilities. The representativeness of emission samples was evaluated on the basis of the variability in technologies and associated release rates among individual facilities in the source category. The more variability among facilities; the more important it is to test multiple facilities. In other cases, although no direct emission measurements were available, estimates could be derived using indirect techniques. Obviously, these "indirect" estimates are much more uncertain than those based on direct measurements.

Citation Quality - The quality of the supporting literature varied widely. Whenever possible, only peer reviewed final reports were used. In some cases, however,

Table 3-1. CDD and CDF Air Emission Estimates for West Germany, Austria, United Kingdom, Netherlands, Switzerland, and the United States

Emission Source	West Germany[a] (g TEQ/yr)	Austria[b] (g TEQ/yr)	United Kingdom[c] (g TEQ/yr)	Netherlands[d] (g TEQ/yr)	Switzerland[k] (g/TEQ/yr)	United States[l] (g/TEQ/yr)
Industrial/Municipal Processes						
Pulp and paper mills		4			1 - 5	2.7
Sewage sludge incineration	0.01 - 1.1	<1		0.3		23
Chemical Manuf./Processing Sources						
Organic chemical manufacture				0.5		
Combustion and Incineration Sources						
Incineration/Energy Recovery						
Municipal waste incineration	5.4 - 432	3	1,150	382	90 - 150	3,000
Hazardous waste incineration	0.5 - 72	6	11	16	<1	35
Hospital waste incineration	5.4	4	32	2.1	2 - 3	5,100
Cement kilns						350
Metallurgical Processes						
Tire combustion						0.3
Ferrous metal smelting/refining	1.3 - 18.9	19[g]		30[g]	6 - 16[g]	
Nonferrous metal smelting/refining	38 - 380					230
Scrap electric wire recovery				1.5		
Drum and barrel reclamation					2 - 14[e]	1.7
Power/Energy Generation						
Vehicle fuel combustion - leaded	7.2	<1[e]	613[e]	7.0[e]		
- unleaded	0.8					1.3
- diesel	4.6				3 - 22	85

Table 3-1. CDD and CDF Air Emission Estimates for West Germany, Austria, United Kingdom, Netherlands, Switzerland, and the United States (continued)

Emission Source	West Germany[a] (g TEQ/yr)	Austria[b] (g TEQ/yr)	United Kingdom[c] (g TEQ/yr)	Netherlands[d] (g TEQ/yr)	Switzerland[k] (g/TEQ/yr)	United States[l] (g/TEQ/yr)
Wood burning		70	16	12		40[m] 320[n]
Coal combustion - residential	1.1	<1[i]	989	3.7[i]		
- industrial			301			
- utility			199			
Oil combustion - residential	1.2		2[h]			
Charcoal briquette combustion (residential)	1.8					
TOTAL	67 - 926	<109	3,870[f]	484[j]	100 - 200	9,200

[a] Source: Fiedler and Hutzinger (1992). Single values represent "minimum" and ranges represent "minimum" to "maximum" emission estimates; Basis Year = 1990.
[b] Source: Riss and Aichinger (1993); Basis Year = 1987/88.
[c] Source: ECETOC (1992); Basis Year = 1989.
[d] Source: Koning et al. (1993); Basis Year = 1991.
[e] Total for all fuel types.
[f] Includes 55g TEQ/yr from combustion of "other organic materials" and 16g TEQ/yr from "accidental fires."
[g] Total for all metal industries including sintering processes.
[h] Total of 2g TEQ/yr from "oil burning".
[i] Total of coal combustion from all sources.
[j] Includes 25g TEQ/yr from combustion of PCP-treated wood, 0.2g TEQ/yr from crematoria, 0.3g TEQ/yr from asphalt mixing plants, and 2.7g TEQ/yr. from various high temperature processes such as soil cleaning, fly ash drying, cement production, production of glass/mineral wool, etc.
[k] Source: Schatowitz et al. (1993); Basis Year = 1990.
[l] Source: Estimates generated in this report; mean values listed when available - all ranges listed in Table 3-2.
[m] Estimate for residential wood burning.
[n] Estimate for industrial wood burning.
[o] CDD/CDFs have not been detected in stack gases from U.S. coal-fired utilities; however, CDD/CDFs have been detected in stack gases in Europe. Additional monitoring studies are underway in the United States.
[p] This total includes some sources not shown in this table that have been reported to date only from U.S. sources. See Table 3-2 for a complete listing of U.S. sources.

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Table 3-2. Current CDD and CDF Emission Estimates for the United States

Emission Source	Emissions (g TEQ/yr) to Media															
	Air				Water				Land/Landfill				Product			
	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]
Industrial/Municipal Processes																
Bleached chemical pulp and paper mills	[b]	[b]	[b]	--	74	110	150	H/H	71	100	140	H/H	110	150	210	H/H
Publicly Owned Treatment Works	[c]	[c]	[c]	--					150	210	290	H/H	2.5	3.6	5.0	H/H
Chemical Manuf./Processing/ Use Sources																
Chlorophenols					NEG	NEG	NEG	--	NEG	NEG	NEG	--				
Chlorobenzenes					NEG	NEG	NEG	--	NEG	NEG	NEG	--				
Aliphatic Chlorine Compounds					NEG	NEG	NEG	--								
Dioxazine Dyes/Pigments																
Pesticides																
Combustion and Incineration Sources																
Incineration/ Energy Recovery																
Municipal waste incineration	1,300	3,000	6,700	H/M	NEG	NEG	NEG	--	810	1,800	4,000	M/M	NA	NA	NA	--
Hazardous waste incineration	11	35	110	M/L	NEG	NEG	NEG	--					NA	NA	NA	--
Medical waste incineration	1,600	5,100	16,000	M/L	NEG	NEG	NEG	--					NA	NA	NA	--
Kraft black liquor boilers	0 9	2.7	4.3	H/M	NEG	NEG	NEG	--					NA	NA	NA	--
Sewage sludge incineration	10	23	52	H/M	NEG	NEG	NEG	--					NA	NA	NA	--
Carbon reactivation furnaces	0 06	0.1	0.3	L/M	NEG	NEG	NEG	--	NA	NA	NA	--	NA	NA	NA	--
Cement kilns	110	350	1,100	H/L					7.6	24	76	H/L				
Metallurgical Processes																
Ferrous metal smelting/refining													NEG	NEG	NEG	--
Secondary copper smelting/refining	74	230	740	H/L									NEG	NEG	NEG	--
Secondary lead smelting/refining	0.7	1.6	3.5	M/M									NEG	NEG	NEG	--
Scrap electric wire recovery	NEG	NEG	NEG	--	NEG	NEG	NEG	--	NEG	NEG	NEG	--	NEG	NEG	NEG	--
Drum and barrel reclamation	0.5	1.7	5.4	L/L									NEG	NEG	NEG	--
Power/Energy Generation																
Tire combustion	0.1	0.3	1 0	H/L									NA	NA	NA	--
Vehicle fuel combustion - leaded	[d]	[d]	[d]		NA	NA	NA	--	NA	NA	NA	--	NA	NA	NA	--

Table 3-2. CDD and CDF Emission Estimates for the United States (continued)

Emission Source	Emissions (g TEQ/yr) to Media															
	Air				Water				Land/Landfill				Product			
	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]	Lower	Central	Upper	CR[a]
- unleaded	0.4	1.3	4.1	H/L	NA	NA	NA	--	NA	NA	NA	--	NA	NA	NA	--
- diesel	27	85	270	H/L	NA	NA	NA	--	NA	NA	NA	--	NA	NA	NA	--
Wood burning - residential	13	40	63	H/M	NA	NA	NA	--					NA	NA	NA	--
- industrial	100	320	1,000	H/L									NA	NA	NA	--
Coal combustion - residential					NA	NA	NA	--					NA	NA	NA	--
- industrial													NA	NA	NA	--
- utility													NA	NA	NA	--
Oil combustion - residential					NA	NA	NA	--					NA	NA	NA	--
Charcoal briquette combustion (residential)					NA	NA	NA	--					NA	NA	NA	--
Reservoir Sources Pentachlorophenol treated surfaces																
Forest fires	27	86	270	M/L	NA	NA	NA	--					NA	NA	NA	--
TOTAL[e]	3,300	9,300	26,000		74	110	150		1,000	2,100	4,500		110	150	220	

[a] CR = Confidence rating. First letter is rating assigned to "production" estimate; second letter is rating assigned to "emission factor" (see Section 3.1 and Table 3-3 for details):
H = High Confidence,
M = Medium Confidence,
L = Low Confidence.

[b] See Kraft black liquor boilers below.

[c] See Sewage sludge incineration below.

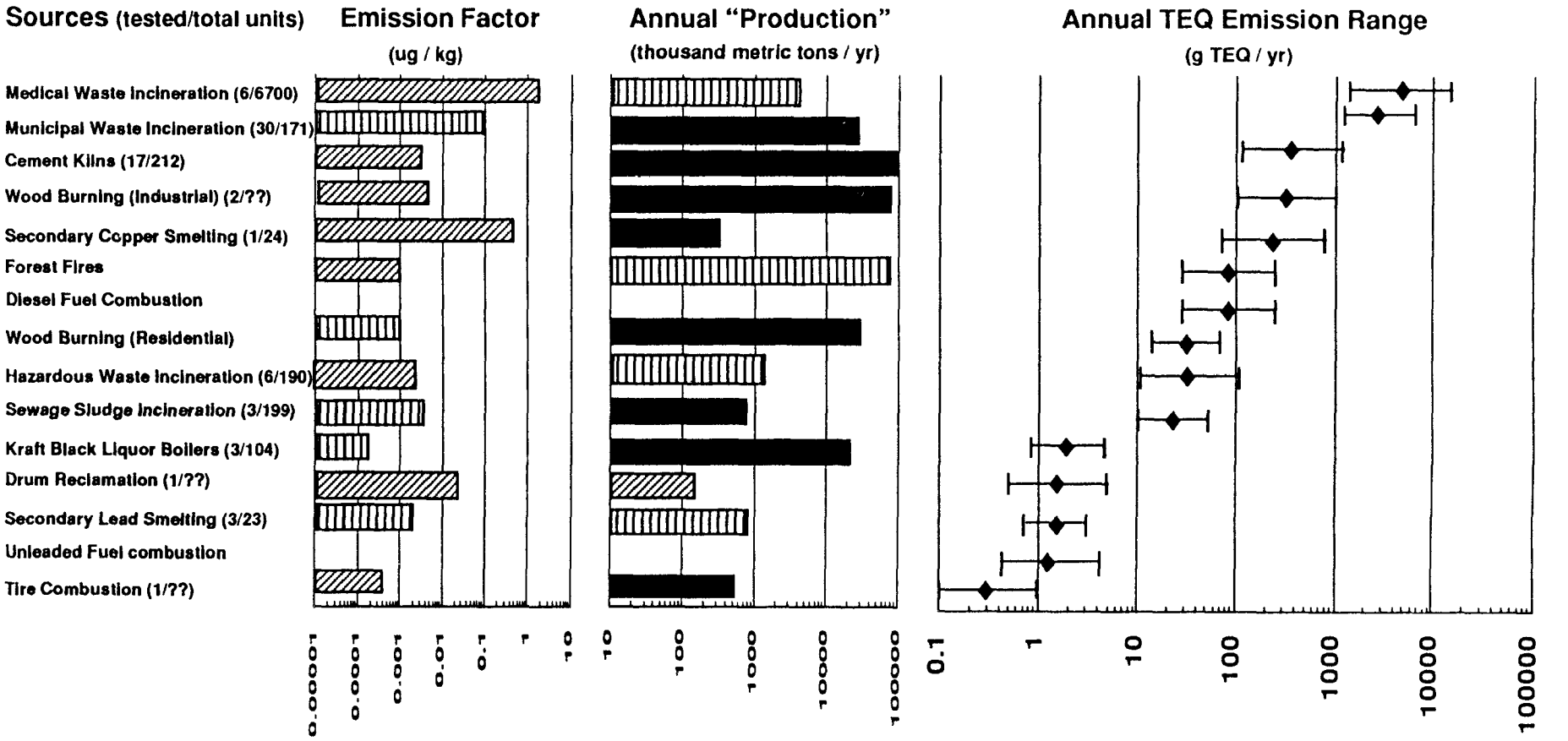
[d] Leaded fuel production in the United States and the manufacture of motor vehicle engines requiring leaded fuel have been prohibited in the United States. (See Section 3.6.13 for details.)

[e] TOTAL reflects only the total of the estimates made in this report. There are many unknowns as reflected by the number of blank cells.

[f] It is not known what fraction, if any, of the estimated emissions from forest fires represents a "reservoir" source. The estimated emissions may be solely the result of combustion.

NA = Not applicable.
NEG = Expected to be negligible or non-existent.
BLANK = Insufficient data available upon which to base an estimate.

Figure 3-1. Estimated TEQ Emissions to Air from Combustion Sources in the United States



Derivation of emission factors and annual "production" (e.g., kg of waste incinerated) are presented in the following sections of Chapter 3. The emission factors for diesel fuel and unleaded fuel combustion are based on ug of TEQ per km driven. The difference in bar shading indicates the degree of confidence in the estimate. The set of numbers following the source categories indicates the number of facilities for which stack test data are available versus the number of facilities in the category.

Legend

Low Confidence | Medium Confidence | High Confidence

DRAFT--DO NOT QUOTE OR CITE

draft reports that had undergone some review were used. In a few cases, unpublished references were used such as personal communication with experts.

The confidence rating scheme, presented in Table 3-3, provides criteria for assigning a "high," "medium," or "low" confidence rating for both the emission factor and production terms. As shown in Table 3-2, confidence ratings have been assigned to each emission estimate. The first rating applies to the "production" term, and the second rating applies to the "emission factor" term. In addition to the confidence rating, the uncertainty in these national release estimates is reflected by presenting, where possible, for each source category both a central or "best guess" value and a possible range from a lower to upper estimate. These lower and upper estimates are not intended to be absolute bounds, but reasonable estimates of how much higher or lower the true value might be. Insufficient data were available to statistically derive these ranges. Therefore, a judgement-based approach was developed. This approach uses the average or best guess estimate as the central value of the range (assumed to be a geometric average) and sets the width of the range on the basis of the confidence class as follows:

- Low confidence class: upper end of range is 10 times higher than lower end;
- Medium confidence class: upper end of range is 5 times higher than lower end;
- High confidence class: upper end of range is 2 times higher than lower end.

This approach initially assumes that the range of uncertainty is symmetrical about the central value. However, in some cases it may be more reasonable to shift the uncertainty range upwards or downwards. For example, it may be reasonable to shift the range downwards in cases where there is strong evidence that upgrades have occurred since the emissions testing. Alternatively, it is possible that the range should be shifted upwards if it can be shown that the tested facilities are more representative of the low emitting facilities than the high emitting facilities. It is emphasized that these ranges

Table 3-3. Confidence Rating Scheme for U.S. Emission Estimates

Confidence Rating	Production Estimate	Emission Factor Estimate
High	Derived from comprehensive survey	Derived from comprehensive survey
Medium	Based on estimates of average plant size and number of plants or limited survey	Derived from limited survey of few facilities representative of sector
Low	Based on expert judgement or unpublished estimates	Derived from similar industry sectors or foreign surveys where differences in industry practices are likely or are based on input measurements rather than actual emissions

should be interpreted as judgements which are symbolic of the relative uncertainty among sources, not statistical measures. The remainder of this chapter reviews the available data for estimating CDD/CDF releases from specific source categories and provides the basis for the emission estimates presented in Table 3-2 for the United States.

3.2. PULP AND PAPER MILLS

3.2.1. Bleached Chemical Wood Pulp and Paper Mills

During 1988, EPA and the U.S. pulp and paper industry jointly conducted a survey of 104 pulp and paper mills in the United States to measure levels of dioxins in effluent, sludge, and pulp (U.S. EPA, 1990a). This study, commonly called the 104-Mill Study, was managed by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) with oversight by EPA, and included all U.S. mills where chemically produced wood pulps are bleached with chlorine or chlorine derivatives.

In 1992, the pulp and paper industry conducted its own NCASI-coordinated survey. The collected data were summarized and analyzed in a report entitled "Summary of Data Reflective of the Pulp and Paper Industry Progress in Reducing the TCDD/TCDF Content of Effluents, Pulps, and Wastewater Treatment Sludges" (NCASI, 1993). Although the report is available from NCASI, it has not been peer reviewed nor published in an independent journal. The data used in the report were provided by individual pulp and paper companies and neither NCASI nor EPA can vouch for the accuracy or representativeness of the data. However, NCASI (1993) reports that the pulp and paper industry has taken numerous steps to reduce CDD/CDF releases since 1988, and that NCASI considers the 1992 survey to be more reflective of current conditions than the data generated in the 104-Mill Study (U.S. EPA, 1990a).

As part of its ongoing efforts to develop revised effluent guidelines and standards for the pulp, paper, and paperboard industry, EPA recently published the Development Document for the guidelines and standards being proposed for this industry (U.S. EPA, 1993d). The Development Document presents estimates of the 2,3,7,8-TCDD and 2,3,7,8-TCDF annual discharges in wastewater from the mills in this industry as of

January 1, 1993. EPA used the most recent information about each mill from four data bases (104-Mill Study, EPA short-term monitoring studies at 13 mills, EPA long-term monitoring studies at 8 mills, and industry self-monitoring data submitted to EPA) to estimate these discharges. The 104-Mill Study data were used only for those mills that did not report making any process changes subsequent to the 104-Mill Study and did not submit any more recent effluent monitoring data. For the purpose of this report, the release estimates from NCASI (1993) and U.S. EPA (1990a) are presented to show the possible range of releases within recent years, but the U.S. EPA (1993d) estimates are believed to be most reflective of current conditions.

NCASI (1993) found that less than 10 percent of mills had 2,3,7,8-TCDD and 2,3,7,8-TCDF concentrations in effluent above the nominal detection limits of 10 ppq and 100 ppq, respectively. Similar results were obtained in the short- and long-term sampling reported for 18 mills in U.S. EPA (1993d). 2,3,7,8-TCDD was detected at four mills, and 2,3,7,8-TCDF was detected at nine mills. Wastewater sludges at most mills (75 to 90 percent) were reported by NCASI (1993) to contain less than 10 ppt of 2,3,7,8-TCDD and less than 100 ppt of 2,3,7,8-TCDF. U.S. EPA (1993d) reported similar results but did find detectable levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF in sludges from 64 percent and 85 percent of the facilities sampled, respectively. NCASI (1993) reported that nearly 90 percent of the bleached pulps contained less than 2 ppt of 2,3,7,8-TCDD and less than 20 ppt of 2,3,7,8-TCDF. The final levels in white paper products would correspond to levels in bleached pulp, so bleached paper products would also be expected to contain less than 2 ppt of 2,3,7,8-TCDD. Overall, NCASI (1993) reports a 90 percent reduction in TEQ generation from 1988 to 1992.

The 104-Mill Study and the NCASI study measured only 2,3,7,8-TCDD and 2,3,7,8-TCDF because these two congeners are the primary contributors (90 percent or more) to the TEQ total found in pulp, sludge, and effluent (U.S. EPA, 1990b). Ninety-four mills participated in the NCASI study, and the remaining 10 (of 104) were assumed by NCASI to be operating at the same levels as measured in the 1988 104 Mill Study. All not detected values were counted as half the detection limit. If detection limits were not

reported, they were assumed to be 10 ppq for effluent and 1 ppt for sludge or bleached pulp.

The U.S. annual discharge rates of 2,3,7,8-TCDD, 2,3,7,8-TCDF, and TEQs due to these two compounds are summarized in Table 3-4 for each study. As stated previously, the 1993 discharge estimate for effluent (U.S. EPA, 1993d) is believed to be the best estimate of current emissions. During the period between the conduct of the 104 Mill Study and the issuance of the U.S. EPA Development Document (U.S. EPA, 1993d), the U.S. pulp and paper industry has reduced releases of CDD/CDFs primarily by instituting numerous process changes to reduce the formation of CDD/CDFs during the production of chemically bleached wood pulp. U.S. EPA (1993d) did not provide extensive sampling of sludge and pulp samples from bleached chemical wood pulp and paper mills comparable to that provided for effluents. However, because most of the reduction between 1988 and 1993 can be attributed to process changes of a pollution prevention nature, the percentage reduction observed in effluent emissions (from 356 g TEQ/yr to 105 g TEQ/yr or 70 percent reduction) is likely representative of the reduction that has been achieved in sludge and pulp emissions over this same time period. Table 3-4 presents best estimates of emissions in sludge and pulp of 100 g TEQ/yr and 150 g TEQ/yr, respectively, using this assumption. The confidence ratings for these release estimates were judged to be H/H based on the fact that direct measurements have been made at virtually all facilities, indicating a high level of confidence in both the production and emission factor estimates. Based on these high confidence ratings, the estimated ranges of potential annual emissions for effluent, sludge, and pulp are assumed to vary by a factor of 2 between the low and high ends of the ranges. Assuming that the best estimates of annual emissions (i.e., the 1993 discharge-based estimates presented in Table 3-4) are the geometric means of these ranges, then the ranges are calculated to be 74 to 150 g TEQ/yr for effluent, 71 to 140 g TEQ/yr for sludge, and 105 to 210 g TEQ/yr for pulp.

In 1990, approximately 20.5 percent or 500 million dry kg of the pulp and paper mill wastewater sludge generated by facilities employing chlorine bleaching of pulp were incinerated (U.S. EPA, 1993e). The majority of the wastewater sludge generated by these facilities is landfilled or placed in surface impoundments (79.5 percent) with the remainder

Table 3-4. Summary of Bleached Chemical Pulp and Paper Mill Discharges of 2,3,7,8-TCDD and 2,3,7,8-TCDF

Matrix	Congener	1988 Discharge[a] (g/year)	1992 Discharge [a] (g/year)	1993 Discharge[b] (g/year)
Effluent	2,3,7,8-TCDD	201	23	71
	2,3,7,8-TCDF	1,550	113	341
	TEQ	356	34	105
Sludge[c]	2,3,7,8-TCDD	210	14	NR
	2,3,7,8-TCDF	1,320	285	NR
	TEQ	343	42	100
Pulp	2,3,7,8-TCDD	262	25	NR
	2,3,7,8-TCDF	2,430	128	NR
	TEQ	505	38	150

NR = Not reported.

[a] Total discharge rate of congener or TEQ (based only on 2,3,7,8-TCDD and 2,3,7,8-TCDF concentration) summed across all 104 mills. The daily discharge rates reported in NCASI (1993) were multiplied by a factor of 365 days/yr to obtain estimates of annual discharge rates.

[b] The discharge in effluent was estimated in U.S. EPA (1993d) for January 1, 1993. The TEQ discharges in sludge and pulp were estimated by multiplying the 1988 discharge estimates for each by the ratio of the 1993 and 1988 effluent discharge estimates (i.e., the estimate of the reduction in 1988 discharges achieved by pollution prevention measures taken by the industry between 1988 and 1993).

[c] Approximately 20.5 percent of the sludge generated in 1990 were incinerated. The remaining 79.5 percent were predominantly landfilled (56.5 percent) or placed in surface impoundments (18.1 percent); 4.1 percent were land-applied directly or as compost and 0.3 percent were distributed/marketed (U.S. EPA, 1993e).

Source: NCASI (1993); U.S. EPA (1993d).

incinerated (20.5 percent), applied to land directly or as compost (4 percent), or distributed as a commercial product (less than 1 percent) (U.S. EPA, 1993e). Black liquor recovery boilers used in the Kraft process for the production of paper pulp are potential sources of CDDs/CDFs. Estimates of potential CDD/CDF emissions to air from these sources are discussed in Section 3.6.4.

3.2.2. Nonchemical and Nonwood Pulping and Bleaching Mills

Although the EPA Office of Water does not believe that secondary fiber mills (i.e., mills using recycled paper as a source of pulp) are significant sources of CDDs and CDFs, EPA is considering whether to establish effluent limitations guidelines and standards for CDD/CDFs for these mills based primarily upon data generated for the Development Document (U.S. EPA, 1993d). These data, collected by EPA or provided to EPA by industry, indicate detectable levels of 2,3,7,8-TCDD in the effluents of 2 of the 12 mills with reported monitoring data and detectable levels of 2,3,7,8-TCDF in the effluents of 4 of the 7 mills with data (U.S. EPA, 1993d).

Data on the presence of more chlorinated (i.e., penta-through octachlorinated) CDDs and CDFs in the effluents of these facilities were not generated for the Development Document (U.S. EPA, 1993d). However, Berry et al. (1993) reports that trace levels of these higher chlorinated homologs were commonly observed in the effluents from Canadian pulp mills that use recycled paper for fiber furnish (i.e., the raw materials used to manufacture pulp) and/or that do not practice chlorine bleaching. Similar results were reported by Rappe et al. (1990). The congener profile observed is not dominated by the tetra-CDDs/CDFs, as is the case with bleach plant wastewater, but rather by the higher chlorinated congeners more consistent with the congener profile found in ambient air, soil, and adipose tissue. These results lead to the hypothesis that paper and paperboard products, during their useful life, can accumulate trace amounts of CDD/CDFs from the ambient environment.

As a step in evaluating this hypothesis, Berry et al. (1993) analyzed the CDD/CDF content of pulp and paper samples from Canadian mills that use neither chlorine-containing bleaching compounds nor fibers that have been bleached with chlorine-containing

compounds as well as papers from mills that use recycled paper as a furnish. All samples analyzed had detectable levels of one or more CDD/CDFs. The congener profiles of the samples were similar with the higher chlorinated congeners dominating in terms of concentration. The order of degree of contamination on a TEQ basis, from high to low, is recycled linerboard (1 sample--2.5 ng TEQ/kg) > "totally chlorine-free" bleached kraft paper (1 sample--0.35 ng TEQ/kg) > pulp from de-inked recycled paper (1 sample--0.19 ng TEQ/kg) > newsprint (17 samples--mean = 0.07 ng TEQ/kg) > unbleached kraft paper (2 samples--mean = 0.02 ng TEQ/kg). Rappe et al. (1990) also reported finding higher levels of CDD/CDFs, particularly the hepta- and octa-chlorinated congeners, in recycled paper pulps than in virgin bleached and unbleached pulps. Based on the results of their study, Berry et al. (1993) concluded that, although it may be possible to produce a dioxin-free pulp, it is likely that all papers will become contaminated during their first life cycle by contact with dioxin-laden dust, and contamination is inevitable if they are recycled multiple times.

3.2.3. Ongoing Regulatory Investigations

The U.S. EPA is currently under court order to develop revised effluent guidelines (i.e., Best Available Technology and Pretreatment Standards for Existing Sources) for the chemical pulping and bleaching subcategories of the pulp and paper industry. These revised effluent guidelines and standards which address control of CDDs and CDFs from bleached chemical wood pulp and paper mills were proposed by EPA on December 17, 1993 (Federal Register, 1993a). In addition, the Clean Air Act Amendments of 1990 require EPA to promulgate Most Achievable Control Technology (MACT) standards for hazardous air pollutants from this industry by 1997. To that end, the Office of Air and Radiation, in coordination with the Office of Water, proposed control technology standards for non-combustion sources on December 17, 1993, (Federal Register, 1993a) and will propose control technology standards for combustion sources by October 1994 with promulgation of both by September 1995 (U.S. EPA, 1992d).

Based on the results of an in-depth risk assessment, EPA's Office of Solid Waste concluded that dioxin contained in pulp and paper mill sludges does not pose an

unreasonable probability of adverse effects on human health and the environment when disposed in landfills and surface impoundments and that further regulation of these facilities under Subtitle D of the Resource Conservation and Recovery Act (RCRA) to reduce potential dioxin-related risks was not warranted (U.S. EPA, 1991a).

However, EPA did find that improper land application of pulp and paper mill sludge for soil conditioning purposes can pose a significant risk to wildlife. In 1991, EPA proposed a regulation under the Toxic Substances Control Act (TSCA) to limit the concentration of CDDs/CDFs in soil conditioned with sludge and also to establish site management practices for land application of the sludge. EPA deferred finalizing the rule until issuance of the final integrated regulations for effluent guidelines and MACT standards. These regulations could make TSCA rulemaking unnecessary. In the interim, EPA is negotiating a voluntary agreement with the American Forest and Paper Association to establish CDD/CDF standards and management practices for the use of sludge as a conditioner (U.S. EPA, 1993b).

3.3. PUBLICLY OWNED TREATMENT WORKS (POTWs)

3.3.1. Sources of CDDs/CDFs

CDD/CDFs have been measured in sewage sludge, though the origins have not been well established. In fact, Oberg et al. (1992) reported that low levels of HpCDDs and OCDD are formed, probably as a result of microbial action, in aerated sewage sludge spiked with pentachlorophenol. Potential sources of the CDD/CDFs include industrial inputs, runoff to sewers from lands or urban surfaces contaminated by product uses or deposition of emissions from combustion sources, household wastewater, chlorination operations within the wastewater treatment facility, or a combination of all the above (Rappe, 1992a; Rappe et al., 1989; Horstmann et al., 1992). The major source(s) for a given treatment plant is likely to be site-specific. For example, Rieger and Ballschmiter (1992) traced the origin of CDDs and CDFs found in municipal sewage sludge in Ulm, Germany, to metal manufacturing and urban sources. The characteristics of both sources were similar and suggested generation via thermal processing. The presence of CDD/CDFs

in sewage sludge suggests that CDD/CDFs may also be present in the wastewater effluent discharges of POTWs; however, no published studies reporting the results of effluent analyses for CDD/CDFs could be found.

In a series of recent studies, Horstmann et al. (1992; 1993a; 1993b) and Horstmann and McLachlan (1994) demonstrated that wastewater from household washing machines could be the major source at many, if not all, POTWs that serve primarily residential populations. Horstmann et al. (1992) provided initial evidence that household wastewater could be a significant source. Horstmann et al. (1993a) measured CDD/CDF levels in the effluent from four different loads of laundry from two different domestic washing machines. The concentrations of total CDD/CDF in the four samples ranged from 3,900 to 7,100 pg/L and were very similar in congener profile with OCDD being the dominant congener followed by the hepta- and hexa-CDDs. Based on the similar concentrations and congener profiles found, Horstmann et al. (1993a) concluded that the presence of CDD/CDF in washing machine wastewater is widespread. A simple mass balance performed using the results showed that the CDD/CDFs found in the four washing machine wastewater samples could account for 27 to 94 percent of the total CDD/CDF measured in the sludge of the local wastewater treatment plant (Horstmann and McLachlan, 1994).

Horstmann et al. (1993a) also performed additional experiments that showed that detergents, commonly used bleaching agents, and the washing cycle process itself were not responsible for the observed CDD/CDFs. Rappe and Andersson (1992) had previously reported that wastewater from clothing and dish washing machines in which sodium hypochlorite-containing detergents were used contained low levels of CDD/CDFs.

To determine if the textile fabric or fabric finishing processes could account for the observed CDD/CDFs, Horstmann et al. (1993b) analyzed the CDD/CDF content of eight different raw (unfinished) cotton cloths containing fiber from different countries and five different white synthetic materials (acetate, viscose, bleached polyester, polyamide, and polyacrylic). The maximum concentrations found in the textile fabrics were 30 ng/kg in the cotton products and 45 ng/kg in the synthetic materials. Also, a cotton finishing scheme was developed in which one of the cotton materials was subjected to a series of

16 typical cotton finishing processes; one sample was analyzed following each step. The fabric finishing processes showing the greatest effect on CDD/CDF concentration were the application of an indanthrene dye and the "wash and wear" finishing process which together resulted in a CDD/CDF concentration of about 100 ng/kg. Based on the concentrations found, the authors concluded that neither unfinished new fabrics nor common cotton finishing processes can explain the CDD/CDF levels found in wastewater.

Horstmann and McLachlan (1994) analyzed 35 new textile samples, primarily cotton products, for CDD/CDFs. Low levels were found in many cases (total CDD/CDF less than 50 ng/kg). However, several colored T-shirts from a number of clothing producers had extremely high levels, with concentrations up to 290,000 ng/kg. Because the concentrations in identical T-shirts purchased at the same store varied by up to a factor of 20, the authors concluded that the source of CDD/CDFs is not a textile finishing process because a process source would have resulted in a more consistent level of contamination.

Horstmann and McLachlan (1994) conducted additional experiments that demonstrated that the small percentage of clothing items with high CDD/CDF levels could be responsible for the quantity of CDD/CDFs observed in household wastewater and sewage sludge. They were able to demonstrate that the CDD/CDFs can be gradually removed from the fabric during washing, can be transferred to the skin and subsequently transferred back to other textiles and then washed out, or can be transferred to other textiles during washing and then removed during subsequent washings.

3.3.2. Releases of CDDs/CDFs

EPA conducted the National Sewage Sludge Survey in 1988 to obtain national data on sewage sludge quality and management. As part of this survey, EPA analyzed sludges from 175 POTWs for CDD/CDF content; sludges from 15 of the POTWs had detectable levels of 2,3,7,8-TCDD. All sludges had detectable levels of at least one CDD/CDF congener (Rubin and White, 1992). TEQ concentrations ranged from 0.7 to 1,816 ng TEQ/kg dry weight. If all not detected values are assumed to be zero, then the mean and median concentrations are 50 and 9 ng TEQ/kg, respectively. If the not detected values

are set equal to the detection limit, then the mean and median concentrations are 86 and 50 ng TEQ/kg, respectively (Rubin and White, 1992).

Approximately 5.4 million dry metric tons of sewage sludge are estimated by EPA to be generated annually in the United States (Federal Register, 1993b). Table 3-5 lists the volume of sludge disposed annually by use and disposal practices. Table 3-5 also lists the estimated amount of TEQs that may be present in sewage sludge and potentially be released to the environment. These values were estimated using the mean TEQ concentration value (not detected values assumed to be zero) reported by Rubin and White (1992) (i.e., 50 ng TEQ/kg). Multiplying this mean concentration by the sludge volumes generated, yields an annual potential total release of 208 grams of TEQ for nonincinerated sludges. Of this 208 grams of TEQ, 3.6 grams enter commerce as a product for distribution and marketing. The remainder is applied to land or is landfilled.

This release estimate is assigned a H/H confidence rating indicating high confidence in both the production and emission factor estimates. The high rating was based on the judgement that the 175 tested facilities were reasonably representative of the variability in the POTW technologies and sewage characteristics. Based on this high confidence rating, the estimated range of potential annual emissions is assumed to vary by a factor of 2 between the low and high ends of the range. Assuming that the best estimate of annual emission to land (105 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 145 to 290 g TEQ/yr. Assuming that the best estimate of 3.6 g TEQ annual emissions in product (i.e., the fraction of sludge that is distributed and marketed as a product) is the geometric mean of the range, then the range is calculated to be 2.5 to 5.0 g TEQ/yr.

An additional 10 to 52 grams of TEQ (central estimate of 23 g TEQ/yr) are estimated to be released to the atmosphere annually by the incineration of sewage sludge. The basis of these incineration release estimates is presented in Section 3.6.5. It is interesting to note that CDDs and CDFs detected in ambient air in Ohio have been linked to sewage sludge combustion (Edgerton et al., 1989). In this study, total CDD/CDF in ambient air ranged from 1,900 to 9,900 fg/m^3; no 2,3,7,8-TCDD was detected in any of the samples with a detection limit of less than 820 fg/m^3.

Table 3-5. Quantity of Sewage Sludge Disposed Annually by Primary, Secondary, or Advanced Treatment POTWs and Potential Dioxin TEQ Releases

Use/Disposal Practice	Volume Disposed (thousands of dry metric tons/year)	Percent of Total Volume	Potential Dioxin Release[c] (g of TEQ/yr)
Land Application	1,714	32.0	85.7
Distribution and Marketing	71	1.3	3.6
Surface Disposal Site/Other	396	7.4	19.8
Sewage Sludge Landfill	157	2.9	7.8
Co-Disposal Landfills[a]	1,819	33.9	91.0
Sludge Incinerators and Co-Incinerators[b]	865	16.1	1.0
Ocean Disposal	(336)[d]	(6.3)[d]	(0)[d]
TOTAL	5,357	100.0	209

a Landfills used for disposal of sewage sludge and solid waste residuals.

b Coincinerators treat sewage sludge in combination with other combustible waste materials.

c Potential dioxin TEQ release for non-incinerated sludges was estimated by multiplying the sludge volume generated (i.e., column 2) by the mean dioxin TEQ concentrations in sludge reported by Rubin and White (1992) (i.e., 50 ng/kg dry weight).

d The Ocean Dumping Ban Act of 1988 generally prohibited the dumping of sewage sludge into the ocean after December 31, 1991. Ocean dumping of sewage sludge ended in June 1992 (Federal Register, 1993). The current method of disposal of the 336 thousand metric tons of sewage sludge that were disposed in the oceans in 1988 has not been determined.

Sources: Federal Register (1989); Federal Register (1993b); Rubin and White (1992)

3.4. CHEMICAL MANUFACTURING AND PROCESSING SOURCES

3.4.1. Manufacture of Halogenated Organic Chemicals - Overview

Several chemical production processes have been shown to generate CDDs and CDFs (Versar, 1985; Hutzinger and Fiedler, 1991a). CDDs and CDFs can be formed during the manufacture of chlorophenols, chlorobenzenes, and chlorobiphenyls (Versar, 1985; Ree et al., 1988). Consequently, disposal of industrial wastes from manufacturing facilities producing these compounds may result in the release of CDDs and CDFs to the environment. Also, the products themselves may contain these compounds, and when used/consumed, may result in additional releases to the environment. CDD and CDF congener distribution patterns indicative of noncombustion sources have been observed in sediments in southwest Germany and the Netherlands. The congener patterns found suggest that wastes from the production of chlorinated organic compounds may be important sources of CDD and CDF contamination in these regions (Ree et al., 1988). The production and use of many of the chlorophenols, chlorophenoxy herbicides, and PCB products have been banned or strictly regulated in most countries. However, these products may have been a source of the environmental contamination that occurred prior to the 1970s and may continue to be a source of environmental releases based on limited use and disposal conditions (Rappe, 1992a).

3.4.1.1. *Chlorophenols*

The two major manufacturing processes used to produce chlorophenols include: (1) electrophilic chlorination of phenol by chlorine gas in the presence of catalytic amounts of aluminum chloride and organic chlorination promoters and stabilizers; and (2) alkaline hydrolysis of chlorobenzenes using aqueous methanolic sodium hydroxide and heat (Ree et al., 1988). CDD and CDF formation is promoted by the high temperatures and/or alkaline conditions used in these processes. CDDs and CDFs may be formed by nucleophilic substitution, radical reactions, and pyrolysis mechanisms (Versar, 1985; Ree et al., 1988).

The major CDD/CDF congeners generated by chlorophenol manufacture are the hexa- through octa-chlorinated congeners (Versar, 1985).

The concentrations of CDD/CDFs in chlorophenols analyzed in the 1970s and early 1980s were assembled and summarized by Versar (1985) and Hutzinger and Fiedler (1991a). Hagenmaier and Brunner (1987) reported the results of analyses of four pentachlorophenol products commercially available during the late 1980s; the total TEQ concentrations in these four products ranged from 0.08 to 2.32 mg/kg. Table 3-6 presents a summary of the data from these three studies. No more recent data on concentrations of CDDs and CDFs in chlorophenols could be found in the literature. However, the mono- through tetra- substituted chlorophenols and bromophenols are subject to reporting under the Dioxin/Furan Test Rule (discussed in Section 3.4.2) and/or the Dioxin/Furan Pesticide Data Call-In. (See Section 3.4.3.) CDDs and CDFs have also been found in numerous chlorophenol-based biocides according to Versar (1985) and Hutzinger and Fiedler (1991a). (See Section 3.4.3 for information on current EPA efforts to obtain data on contamination levels in pesticides.)

Several studies have provided evidence of localized environmental contamination resulting from the production or use of chlorophenols. For example, Tong et al. (1990) observed that sediment samples collected from a site near a chemical manufacturing facility where 2,4,5-T had been synthesized were highly contaminated with CDDs and CDFs. In addition, the CDD and CDF congener distribution pattern in the sediment was similar to that of 2,4,5-T, suggesting the manufacture found in 2,4,5-T as a primary source of contamination.

As indicated in Table 3-6, pentachlorophenol (PCP) products have been reported to be the most contaminated chlorophenol products. The major congener found in PCP is OCDD, but lower chlorinated congeners are also found (Rappe et al., 1987; Hutzinger and Fiedler, 1991a). High levels of CDD/CDFs have also been found in sludges from the production of PCP (Versar, 1985; Hutzinger and Fiedler, 1991a). McKee et al. (1990) surveyed harbor sediments adjacent to a wood preserving plant in Ontario, Canada, that uses PCP and creosote. Sediments were contaminated with hexa-, hepta-, and octa-chlorinated CDD/CDFs. The highest levels observed were: 5.7 ng/g HxCDD, 320 ng/g

Table 3-6. Concentration Ranges of CDD/CDF Homologue Groups in Chlorophenols[a] (ppm)

Chloro-phenol	DCDD	TrCDD	TCDD	PeCDD	HxCDD	HpCDD	OCDD
2-	ND	ND	0.037	ND	ND	ND	ND
2,4-	ND	ND	ND	ND	ND	ND	ND
2,6-	ND	ND	ND	ND	ND	ND	ND
2,4,5-	ND-0.72	ND	ND-6.20	ND-1.50	<1.0	<1.0	<1.0
2,4,6-	NA	ND-93	ND-49	<0.10	<1.0	<1.0	<1.0
2,3,4,6-	ND	ND	<0.10	<0.10	ND-29	ND-10.0	ND-2.0
penta	ND	ND	ND-1.25	ND-0.08	0.02-42	0.50-870	3.3-3,660
Chloro-phenol	**DCDF**	**TrCDF**	**TCDF**	**PeCDF**	**HxCDF**	**HpCDF**	**OCDF**
2,4,6-	NA	NA	1.5-17.5	0.7-36	0.02-36	4.8	<1
1,3,4,6-	NA	NA	0.5	10	70	70	10
penta	NA	NA	0.01-0.9	0.03-40	0.03-100	0.5-400	1.1-260

[a] Data originally reported in the 1970s and 1980s.
ND = Not detected (detection limit typically 1 ppm).
NA = Not analyzed or not reported.

Sources: Hutzinger and Fiedler (1991a); Versar (1985); Hagenmaier and Brunner (1987).

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HpCDD, 980 ng/g OCDD, 6.5 ng/g HxCDF, and 53 ng/g HpCDF for a site 13 meters from the facility's dock and 400 ng/g OCDF for a site 78 meters from the dock. CDD/CDFs have also been found in composts from a yard waste composting facility in the United Kingdom (Harrad et al., 1991). Past use of PCP-based biocides was suggested as the major source of contamination, based on isomer patterns and empirical evidence.

In the mid-1980s, EPA's Office of Solid Waste promulgated land disposal restrictions on wastes (i.e., wastewaters and non-wastewaters) resulting from the manufacture of chlorophenols (40 CFR 268). Table 3-7 lists all solid wastes in which CDDs and CDFs are regulated as hazardous constituents by EPA, including chlorophenol wastes. The regulations prohibit the land disposal of these wastes until they have been treated to a level below the routinely achievable detection limit of 1 ppb in the waste extract for each of the following congener groups: TCDDs, PeCDDs, HxCDDs, TCDFs, PeCDFs, and HxCDFs (standards for waste code F039 apply only to TCDDs and TCDFs). The treatment standard of 1 ppb is based on incineration to 99.9999 percent destruction and removal efficiency. Section 3.4.3 of this report describes regulatory actions taken by EPA to control the manufacture and use of chlorophenol-based pesticides.

EPA's Office of Water has promulgated effluent limitations for facilities that manufacture chlorinated phenols and discharge treated wastewater (40 CFR 414.70). Although these effluent limitations do not specifically address CDDs and CDFs, the treatment processes required to control the chlorinated phenols that are regulated (2-chlorophenol and 2,4,-dichlorophenol) are expected to control releases of CDDs and CDFs to minimal levels. The effluent limitations for the individual regulated chlorinated phenols are less than or equal to 39 μg/l for facilities that utilize biological end-of-pipe treatment.

3.4.1.2. *Chlorobenzenes*

Chlorobenzenes are manufactured by electrophilic substitution reactions of gaseous chlorine and benzene (Ree et al., 1988). CDD/CDFs may form during the production of these chemicals, but with less probability than in chlorophenol manufacturing (Hutzinger and Fiedler, 1991a). CDD/CDFs form by nucleophilic substitution and pyrolysis mechanisms (Ree et al., 1988). The factors contributing to the production of CDD/CDFs

Table 3-7. Summary of Specific Dioxin-Containing Wastes That Must Comply with Land Disposal Retrictions

EPA Hazardous Waste Number	Waste Description	Land Disposal Restriction Effective Date	Regulated Waste Constitutent	Treatment Standard[a] (ppb)
F020	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri- or tetrachlorophenol, or of intermediates used to produce their pesticide derivatives. (This listing does not include wastes from the production of hexachlorophene from highly purified 2,4,5-trichlorophenol.)	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F021	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of pentachlorophenol, or of intermediates used to produce its derivatives.	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F022	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzenes under alkaline conditions.	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F023	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the production or manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tri- and tetrachlorophenols. (This listing does not include wastes from equipment used only for the production or use of hexachlorophene from highly purified 2,4,5-trichlorophenol.)	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F026	Wastes (except wastewater and spent carbon from hydrogen chloride purification) from the production of materials on equipment previously used for the manufacturing use (as a reactant, chemical intermediate, or component in a formulating process) of tetra-, penta-, or hexachlorobenzene under alkaline conditions.	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1

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Table 3-7. Summary of Specific Dioxin-Containing Wastes That Must Comply with Land Disposal Retrictions (continued)

EPA Hazardous Waste Number	Waste Description	Land Disposal Restriction Effective Date	Regulated Waste Constitutent	Treatment Standard[a] (ppb)
F027	Discarded unused formulations containing tri-, tetra-, or pentachlorophenol or discarded unused formulations containing compounds derived from these chlorophenols. (This listing does not include formulations containing hexachlorophene synthesized from prepurified 2,4,5-trichlorophenol as the sole component.)	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F028	Residues resulting from the incineration or thermal treatment of soil contaminated with EPA Hazardous Waste Nos. F020-F023, F026, and F027	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
F039	Leachate (liquids that have percolated through land disposed wastes) resulting from the disposal of more than one restricted waste classified as hazardous under subpart D of 40 CFR 268. (Leachate resulting from the disposal of one or more of the following EPA Hazardous Wastes and no other Hazardous Wastes retains its EPA Hazardous Waste Number(s): F020, F021, F022, F026, F027, and/or F028.)	August 8, 1990 (wastewater) May 8, 1992 (non-wastewater)	TCDDs TCDFs	<0.063 ppb (wastewater) <1 ppb (non-wastewater) <0.063 ppb (wastewater) <1 ppb (non-wastewater)
K043	2,6-dichlorophenol waste from the production of 2,4-D.	June 8, 1989	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1
K099	Untreated wastewater from the production of 2,4-D.	August 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs	<1 <1 <1 <1 <1 <1

[a]Treatment standards (i.e., maximum allowable concentration in waste extraact) are based on incineration to 99.9999 percent destruction and removal efficiency.

Source: 40 CFR 268

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are: (1) using oxygen as a nuclear substituent; (2) producing or purifying the substance under alkaline conditions; and (3) using reaction temperatures above 150°C (Hutzinger and Fiedler, 1991a).

The concentrations of CDD/CDFs found in single samples of chlorobenzenes by researchers in Germany (Hagenmaier and Brunner, 1987; Hutzinger and Fiedler, 1991a) are listed in Table 3-8. In di-, tri-, tetra-, and penta-chlorobenzene, CDD/CDFs have been detected in the sub-μg/kg range. In hexachlorobenzene, CDD/CDFs have been detected in the μg-mg/kg range. No more recent data on concentrations of CDDs and CDFs in chlorobenzenes could be found in the literature. The limited available published information on CDD/CDF concentrations in chlorobenzene products is not sufficient in quantity (i.e., number of samples) or in detail (i.e., congener-specific results) to enable a reliable estimate to be made of the mass of CDDs/CDFs present in chlorobenzene products even though reliable annual production volume information is available for some products (e.g., 107,526 metric tons of monochlorobenzene and 63,104 metric tons of dichlorobenzene were produced in the United States in 1990) (U.S. ITC, 1991). However, the mono-, di-, and trichlorobenzenes are subject to reporting under the Dioxin/Furan Test rule (Section 3.4.2) and/or the Dioxin/Furan Pesticide Data Call-In (Section 3.4.3).

EPA's Office of Solid Waste has promulgated land disposal restrictions on wastes (i.e., wastewaters and non-wastewaters) resulting from the manufacture of chlorobenzenes (40 CFR 268). Table 3-7 lists all solid wastes in which CDDs and CDFs are regulated as hazardous constituents by EPA, including chlorobenzene wastes. The regulations prohibit the land disposal of these wastes until they have been treated to a level below the routinely achievable detection limit of 1 ppb in the waste extract for each of the following congener groups: TCDDs, PeCDDs, HxCDDs, TCDFs, PeCDFs, and HxCDFs (standards for waste code F039 apply only to TCDDs and TCDFs). The treatment standard of 1 ppb is based on incineration to 99.9999 percent destruction and removal efficiency.

EPA's Office of Water has promulgated effluent limitations for facilities that manufacture chlorinated benzenes and discharge treated wastewater (40 CFR 414.70). Although these effluent limitations do not specifically address CDDs and CDFs, the

Table 3-8. CDD/CDF Concentrations in Chlorobenzenes (μg/kg)

	OCDD	OCDF	HpCDD	HpCDF	HxCDD	HxCDF	PeCDD	PeCDF	TCDD	TCDF	Det. Limit
Hexachloro-benzene (97%)	6,700	2,830	470	455	ND	ND	ND	ND	ND	ND	20
Pentachloro-benzene (pure, 98% C1)	0.05	0.1	0.02	0.1	0.02	ND	ND	ND	ND	0.02	0.02
1,2,4,5-Tetra-chlorobenzene (99% C1)	0.4	2.1	0.8	1.5	0.5	0.8	0.2	0.2	ND	0.03	0.02
1,2,4-Trichloro-benzene	ND-0.08	ND-0.02	ND-0.25	ND-0.03	ND-0.26	ND-0.09	ND-0.14	ND-0.27	ND-0.03	ND-0.74	0.001-0.1
1,2-Dichloro-benzene (for synthesis)	ND	ND	ND	ND	ND	ND	ND	0.5	0.3	ND	0.02
Chlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02

Source: Hagenmeier and Brunner (1987); Hutzinger and Fiedler (1991a)

ND = Not detected.

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treatment processes required to control the chlorinated benzenes that are regulated (chlorobenzene; 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 1,2,4-trichlorobenzene; and hexachlorobenzene) are expected to control releases of CDDs and CDFs to minimal levels. The effluent limitations for the individual regulated chlorinated benzenes are less than or equal to 77 μg/l for facilities that utilize biological end-of-pipe treatment and are less than or equal to 196 μg/l for facilities that do not employ biological end-of-pipe treatment.

3.4.1.3. *Chlorobiphenyls*

PCBs are manufactured by the direct chlorination of biphenyl in the presence of a catalyst. HpCDDs, OCDD, and CDFs, particularly the tetra-, penta-, and hexa-chlorinated CDF congeners, have been detected in commercial PCB formulations (Hagenmaier, 1987) However, the production of PCBs in the United States has been banned under TSCA and the use of in-service PCBs has been dramatically reduced. CDFs can be formed from PCBs under pyrolytic conditions, or by nonpyrolytic conditions via chlorine substitutions on the ortho-positions in the PCB molecule (Ree et al., 1988). Combustion of PCB-containing materials in transformers and capacitors may be a source of PCB-associated CDFs. (See Section 3.5.17.)

3.4.1.4. *Aliphatic Chlorine Compounds*

Aliphatic chlorine compounds are used as monomers in the production of plastics, as solvents and cleaning agents, and as precursors for chemical synthesis (Hutzinger and Fiedler, 1991a). These compounds are produced in large quantities. In 1990, 13.2 million metric tons of chlorinated aliphatic hydrocarbons were produced (U.S. ITC, 1991). The production of 1,2-dichloroethane and vinyl chloride accounted for 85 percent of this total production. Highly chlorinated CDDs and CDFs (i.e., hexa- to octa-chlorinated congeners) have been found in samples of 1,2-dichloroethane (55 ppb of OCDF), tetrachloroethane (47 ppb of OCDD), and epichlorohydrin (88 ppb of CDDs and 33 ppb of CDFs) (Hutzinger and Fiedler, 1991a). Because no more recent or additional data could be found in the

literature to confirm these values, no estimates have been made of the mass of CDDs/CDFs present in these products manufactured annually.

Greenpeace recently issued a report (Greenpeace, 1993) on dioxin emissions associated with the production of ethylene dichloride (EDC) and vinyl chloride monomer (VCM). The Vinyl Institute has responded with a critique of the report (ChemRisk, 1993). Both of these studies are discussed below.

Greenpeace (1993) estimated that plants producing EDC and VCM release 1.8 kg of TEQ/yr to the environment (air, water, and ground combined - possible releases in the final products were not discussed). This estimate was based on an emission factor of 5 to 10 g TEQ/100,000 tons of VCM produced and a worldwide estimate of PVC (and thus VCM) production of 18 million metric tons/yr. This estimate represents the total emissions from all plants in the world but was based on data from only four European plants. Greenpeace (1993) cited some specific information on CDD/CDF formation or releases from a lengthy list of primary references. While most of the specific data came from studies conducted or sponsored by industry, in no case was the information offered by Greenpeace (1993) complete enough to allow calculation of all process or waste stream-specific emission factors to particular environmental media for a given plant.

European PVC manufacturers claim the emission factor is 0.01 to 0.5 g TEQ/100,000 metric tons of VCM, resulting in global emissions from EDC/VCM production as 0.002 to 0.09 kg TEQ/yr (Miller, 1993). There is no apparent dispute between the industry and Greenpeace regarding the formation of CDDs/CDFs during the production process, nor that some CDDs/CDFs are released to various environmental media. However, both European and U.S. manufacturers strongly dispute the total emission factors used in Greenpeace (1993) in arriving at their estimated total of 1.8 kg TEQ/yr emitted world-wide by the PVC industry.

Greenpeace (1993) cites the same specific monitoring information as industry but argues in several case studies that "diffuse emissions" of products and byproducts containing unspecified amounts of CDDs/CDFs constitute a very significant additional source to several environmental media. This appears to be the only rationale presented by Greenpeace (1993) to justify increasing the overall emission factor of 0.01 to 0.5 g

TEQ/100,000 metric tons of VCM produced, which is accepted by European manufacturers, to Greenpeace's 5 to 10 g TEQ/100,000 metric tons.

PVC production in the United States is 4.5 million metric tons per year (ChemRisk, 1993). No data could be found on dioxin levels in waste streams or air emissions from PVC plants in the United States. Applying the worldwide emission factors discussed above to the U.S. PVC industry, gives a range of dioxin emissions of 0.45 to 23 g TEQ/yr (based on the industry emission factors) to 230 to 450 g TEQ/yr (based on the Greenpeace emission factors). It is unclear whether EDC/VCM/PVC production and emission control methods are sufficiently similar worldwide to know whether these factors should apply in the United States. Considering this unknown and the lack of measurement data in general and for U.S. facilities in particular, this report does not endorse either of these emission estimates nor is an independent emission estimate presented. Also, insufficient information was provided to indicate how these emissions, if present in the United States, would separate among media. Monitoring efforts to collect these data are highly recommended.

EPA's Office of Water has promulgated effluent limitations for facilities that manufacture chlorinated aliphatic chlorine compounds and discharge treated wastewater (40 CFR 414.70). Although these effluent limitations do not specifically address CDDs and CDFs, the treatment processes required to control the chlorinated aliphatic compounds that are regulated (e.g., 68 μg/l for 1,2-dichloroethane and 22 μg/l for tetrachloroethylene) are expected to control releases of CDDs and CDFs to minimal levels.

3.4.1.5. *Dyes and Pigments*

CDD/CDF contamination of dioxazine dyes and pigments available in Canada has been observed (Williams et al., 1992). As shown in Table 3-9, OCDD and OCDF concentrations in the μg/g range, and HpCDD, HxCDD, and PeCDD concentrations in the ng/g range were found in Direct Blue 106 dye (3 samples) and Direct Blue 108 dye (1 sample) dyes and Violet 23 pigments (6 samples)(Williams et al., 1992). Dioxazine pigments (e.g., Violet 23 pigment) and dioxazine dyes (e.g., Direct Blue 106 and 108) are derived from chloranil, which has been found to contain high levels of CDD/CDFs and has

Table 3-9. CDD/CDF Levels (μg/kg) in Dioxazine Dyes and Pigments

	Blue 106			Blue 108	Violet 23					
Congener	#1	#2	#3	#1	#1	#2	#3	#4	#5	#6
TCDF (2378)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCDF total	ND	0.3	ND	ND	ND	ND	ND	ND	0.4	ND
PeCDF (12378)	ND	ND	ND	ND	0.5	ND	ND	ND	ND	ND
PeCDF (23478)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PeCDF total	ND	ND	ND	ND	0.5	ND	ND	ND	ND	ND
HxCDF (123678/123478)	12	2	2	ND	76	4	39	31	9	7
HxCDF (23478)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HxCDF total	12	2	2	ND	76	5	39	31	9	7
HpCDF (123478)	50	10	14	9	13	10	11	4	1	12
HpCDF total	71	32	26	12	26	14	29	13	2	21
OCDF	12463	1447	1006	11	941	125	3749	1556	147	425
TCDD (2378)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TCDD total	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PeCDD (12378)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PeCDD total	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HxCDD (123678)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HxCDD (123789)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HxCDD total	ND	ND	ND	1	21	2	7	ND	ND	1
HpCDD (1234678)	31	6	9	ND	9	1	16	10	2	4
HpCDD total	34	8	12	ND	30	5	36	11	2	6
OCDD	41953	28553	18066	23	7180	806	11022	7929	1627	1420
I-TEQ (ng/g)	56.4	30.2	19.5	0.1	16.0	1.4	18.9	12.7	2.7	2.7

Source: Williams et al. (1992)

ND - not detected; analytical detection limit ca. 0.3 μg/kg

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been suggested as the source of contamination among these dyes (Christmann et al., 1989; Williams et al., 1992; U.S. EPA, 1992b). In May 1990, EPA received test results showing that chloranil was heavily contaminated with dioxins; levels as high as 3,065 ppb TEQ were measured (U.S. EPA, 1992b). (See Section 3.4.2 for analytical results.)

Between 1990 and 1992, EPA learned that dioxin TEQ levels in chloranil could be reduced by more than two orders of magnitude (to less than 20 ppb) through manufacturing feedstock and process changes. EPA's Office of Pollution Prevention and Toxics (OPPT) subsequently began efforts to complete an industry-wide switch from use of the contaminated chloranil to low-dioxin chloranil. Although no chloranil is manufactured in the United States, significant quantities are imported. As of June 1993, EPA had negotiated agreements with all chloranil importers and domestic dye/pigment manufacturers known to EPA who use chloranil in their products to switch to low-dioxin chloranil. EPA will issue a significant new use rule (SNUR) under Section 5 of TSCA when U.S. stocks of chloranil with high levels of CDDs/CDFs are depleted. The SNUR will require industry to notify EPA at least 90 days prior to the manufacture, import, or processing, for any use, of chloranil containing total CDDs/CDFs at a concentration greater than 20 ug/kg (Cash, 1993; U.S. EPA, 1993c).

CDD/CDFs (tetra-, penta-, and hexa-chlorinated congeners) in the ppt range were found in Ni-phthalocyanine when several commercial phthalocyanine dyes were analyzed (Hutzinger and Fiedler, 1991a). Phthalocyanine dyes and diarylide yellow pigments have also been observed to contain PCBs in the ppm range. The PCBs are believed to be generated during manufacture because of the use of high-boiling chlorinated aromatic solvents (Hutzinger and Fiedler, 1991a). EPA, however, has prohibited the processing or distribution in commerce of any diarylide and phthalocyanine pigments that contain 50 ppm or more of PCBs (40 CFR 762.20).

3.4.2. Manufacture of Halogenated Organic Chemicals - Dioxin/Furan Test Rule Data

Based on evidence that halogenated dioxins and furans may be formed as by-products during chemical manufacturing processes (Versar, 1985), EPA proposed a rule under Section 4 of the TSCA that would require chemical manufacturers and importers to

test for the presence of chlorinated and brominated dioxins and furans in certain commercial organic chemicals (Federal Register, December 19, 1985). The final rule (Federal Register, June 5, 1987) listed 12 manufactured or imported chemicals for which testing was required and 20 chemicals not currently being manufactured or imported that would require testing if manufacture or importation resumed. These chemicals are listed in Table 3-10. The specific dioxin and furan congeners for which quantitation is required and the target limits of quantitation (LOQ) specified in the Rule are listed in Table 3-11. Under Section 8(a) of TSCA, the final rule also required that chemical manufacturers submit data on manufacturing processes and reaction conditions for chemicals produced using any of the 29 precursor chemicals listed in Table 3-12. The rule stated that subsequent to this data gathering effort, testing may be proposed for additional chemicals if any of the manufacturing conditions used favored the production of dioxins and furans.

To date, data have been submitted to the EPA TSCA Docket for 10 of the 12 chemicals requiring testing, however, not every manufacturer/importer has submitted data for every applicable product (Cash, 1993). Manufacture/import of the other two substances have stopped since the test rule was promulgated. [NOTE: All data and reports in the EPA TSCA Docket are available for public review/inspection at EPA Headquarters in Washington, DC.]

The results of analytical testing for dioxins and furans for the eight chemicals for which data are available in the TSCA docket are presented in Table 3-13. Data submitted for pentabromodiphenyloxide and tetra-bromobisphenol A-bisethoxylate are currently under EPA review. Dioxins/furans were found in four of these eight chemicals. The chemicals for which positive results were obtained are: 2,3,5,6-tetrachloro-2,5-cyclohexadiene-1,4-dione (chloranil), octabromodiphenyloxide, decabromodiphenyloxide, and tetrabromobisphenol-A. Table 3-14 presents the quantitative analytical results for the four submitted chloranil samples as well as the results of verification sampling/analysis performed on chloranil by EPA.

It should be noted that although testing conducted under this test rule for 2,4,6-tribromophenol indicated no halogenated dioxins or furans above the LOQs, Thoma and Hutzinger (1989) reported detecting BDDs and BDFs in a technical grade sample of this

Table 3-10. Chemicals Requiring TSCA Section 4 Testing Under the Dioxin/Furan Rule

Currently manufactured or imported as of June 5, 1987[a]	
CAS No.	Chemical Name
79-94-7	Tetrabromobisphenol-A
118-75-2	2,3,5,6-Tetrachloro-2,5-cyclohexadiene-1,4-dione
118-79-6	2,4,6-Tribromophenol
120-83-2	2,4-Dichlorophenol
1163-19-5	Decabromodiphenyloxide
4162-45-2	Tetrabromobisphenol-A-bisethoxylate
21850-44-2	[a]Tetrabromobisphenol-A-bis-2,3-dibromopropylether
25327-89-3	Allyl ether of tetrabromobisphenol-A
32534-81-9	Pentabromodiphenyloxide
32536-52-0	Octabromodiphenyloxide
37853-59-1	1,2-Bis(tribromophenoxy)-ethane
55205-38-4	[a]Tetrabromobisphenol-A-diacrylate
Not currently manufactured or imported as of June 5, 1987	
CAS No.	Chemical Name
79-95-8	Tetrachlorobisphenol-A
87-10-5	3,4',5-Tribromosalicylanide
87-65-0	2,6-Dichlorophenol
95-77-2	3,4-Dichlorophenol
95-95-4	2,4,5-Trichlorophenol
99-28-5	2,6-Dibromo-4-nitrophenol
120-36-5	2[2,4-(Dichlorophenoxy)]-propanoic acid
320-72-9	3,5-Dichlorosalicyclic acid
488-47-1	Tetrabromocatechol
576-24-9	2,3-Dichlorophenol
583-78-8	2,5-Dichlorophenol
608-71-9	Pentabromophenol
615-58-7	2,4-Dibromophenol
933-75-5	2,3,6-Trichlorophenol
1940-42-7	4-Bromo-2,5-dichlorophenol
2577-72-2	3,5-Dibromosalicylanide
3772-94-9	Pentachlorophenyl laurate
37853-61-5	Bismethylether of tetrabromobisphenol-A
-	Alkylamine tetrachlorophenate
-	Tetrabromobisphenol-B

[a] As of May 4, 1993, tetrabromobisphenol-A-bis-2,3-dibromopropylether and tetrabromobisphenol-A-diacrylate are no longer manufactured in or imported into the United States (Cash, 1993).

Table 3-11. Congeners and Limits of Quantitation (LOQ) for Which Quantitation is Required Under the Dioxin/Furan Test Rule and Pesticide Data Call-In

Chlorinated Dioxins and Furans	Brominated Dioxins and Furans	LOQ
2,3,7,8-TCDD	2,3,7,8-TBDD	0.1 ppb
1,2,3,7,8-PeCDD	1,2,3,7,8-PeBDD	0.5 ppb
1,2,3,4,7,8-HxCDD	1,2,3,4,7,8-HxBDD	2.5 ppb
1,2,3,6,7,8-HxCDD	1,2,3,6,7,8-HxBDD	2.5 ppb
1,2,3,7,8,9-HxCDD	1,2,3,7,8,9-HxBDD	2.5 ppb
1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-HpBDD	100 ppb
2,3,7,8-TCDF	2,3,7,8-TBDF	1 ppb
1,2,3,7,8-PeCDF	1,2,3,7,8-PeBDF	5 ppb
2,3,4,7,8-PeCDF	2,3,4,7,8-PeBDF	5 ppb
1,2,3,4,7,8-HxCDF	1,2,3,4,7,8-HxBDF	25 ppb
1,2,3,6,7,8-HxCDF	1,2,3,6,7,8-HxBDF	25 ppb
1,2,3,7,8,9-HxCDF	1,2,3,7,8,9-HxBDF	25 ppb
2,3,4,6,7,8-HxCDF	2,3,4,6,7,8-HxBDF	25 ppb
1,2,3,4,6,7,8-HpCDF	1,2,3,4,6,7,8-HpBDF	1 ppm
1,2,3,4,7,8,9-HpCDF	1,2,3,4,7,8,9-HpBDF	1 ppm

Table 3-12. Precursor Chemicals Subject to Reporting Requirements Under TSCA Section 8(a)

CAS No.	Chemical Name
85-22-3	Pentabromoethylbenzene
87-61-6	1,2,3-Trichlorobenzene
87-84-3	1,2,3,4,5-Pentabromo-6-chlorocyclohexane
89-61-2	1,4-Dichloro-2-nitrobenzene
89-64-5	4-Chloro-2-nitrophenol
89-69-0	2,4,5-Trichloronitrobenzene
92-04-6	2-Chloro-4-phenylphenol
97-74-6	4-Chloro-o-toloxy acetic acid
94-81-5	4-(2-Methyl-4-chlorophenoxy) butyric acid
95-50-1	o-Dichlorobenzene
95-56-7	o-Bromophenol
95-57-8	o-Chlorophenol
95-88-5	4-Chlororesorcinal
95-94-3	1,2,4,5-Tetrachlorobenzene
95-50-7	5-Chloro-2,4-dimethoxyaniline
99-30-9	2,6-Dichloro-4-nitroaniline
99-54-7	1,2-Dichloro-4-nitrobenzene
106-37-6	Dibromobenzene
106-46-7	p-Dichlorobenzene
108-70-3	1,3,5-Trichlorobenzene
108-86-1	Bromobenzene
108-90-7	Chlorobenzene
117-18-0	1,2,4,5-Tetrachloro-3-nitrobenzene
120-82-1	1,2,4-Trichlorobenzene
348-51-6	o-Chlorofluorobenzene
350-30-1	3-Chloro-4-fluoronitrobenzene
615-67-8	Chlorohydroquinone
626-39-1	1,3,5-Tribromobenzene
827-94-1	2,6-Dibromo-4-nitroaniline

Table 3-13. Results of Analytical Testing for Dioxins and Furans in the Chemicals Tested To-Date Under Section 4 of the Dioxin/Furan Test Rule

CAS Number	Chemical Name	Number of Chemical Companies That Submitted Data	Number of Positive Studies	Congeners Detected
79-94-7	Tetrabromobisphenol-A	3	2	1,2,3,4,7,8/1,2,3,6,7,8-HxBDD 1,2,3,7,8-PeBDF 2,3,4,7,8-PeBDF 1,2,3,4,7,8-HxBDF 1,2,3,4,6,7,8-HpBDF 1,2,3,4,7,8,9-HpBDF
118-75-2	2,3,5,6-Tetrachloro-2,5-cyclohexadiene-1,4-dione (chloranil)	4	4	See Table 3-14
118-79-6	2,4,6-Tribromophenol	1	0	ND[a]
120-83-2	2,4-Dichlorophenol	1	0	ND[a]
1163-19-5	Decabromodiphenyl-oxide	3	2[b]	2,3,7,8-TBDF 1,2,3,7,8-PeBDF 2,3,7,8,9-PeBDF 1,2,3,4,7,8/1,2,3,6,7,8-HxBDF 1,2,3,4,6,7,8-HpBDF
25327-89-3	Allyl ether of tetrabromobisphenol-A	1	0	ND[a]
32536-52-0	Octabromodiphenyl-oxide	3	2[b]	2,3,7,8-TBDD 2,3,7,8-TBDF 1,2,3,7,8-PeBDF 2,3,4,7,8-PeBDF 1,2,3,4,7,8/1,2,3,6,7,8-HxBDF 1,2,3,7,8,9-HxBDF 1,2,3,4,6,7,8-HpBDF
378-53-59-1	1,2-Bis(tribromo-phenoxy)-ethane	1	c	c
32534-81-9	Pentabromodipheny-oxide	2	c	c
4162-45-2	Tetrabromobisphenol-A-bisethoxylate	1	0	ND[a]

[a] No 2,3,7,8-substituted dioxins and furans detected above the Test Rule target limits of quantitation (LOQ). (See Table 3-11.)
[b] Third study is currently undergoing EPA review.
[c] Study is currently undergoing EPA review.

Table 3-14. CDDs and CDFs in Chloranil and Carbazole Violet Samples Analyzed Pursuant to the EPA Dioxin/Furan Test Rule

Congener	Concentration (μg/kg) in Chloranil				Concentration (μg/kg) in Carbazole Violet
	Importer 1	Importer 2	Importer 3	Importer 4	
2,3,7,8-TCDD	nd (1)	nd (1)	nd (2)	nd (2)	nd (0.8)
1,2,3,7,8-PeCDD	nd (2)	nd (2)	nd (5)	nd (6)	nd (0.5)
1,2,3,4,7,8-HxCDD	nd (3)	nd (10)	nd (5)	nd (3)	nd (1.2)
1,2,3,6,7,8-HxCDD	nd (3)	75	nd (5)	6	nd (1.2)
1,2,3,7,8,9-HxCDD	nd (1)	48	nd (5)	9	nd (1.2)
1,2,3,4,6,7,8-HpCDD	110	8,200	390	2,300	28
OCDD	240,000	180,000	760,000	71,000	1,600
2,3,7,8-TCDF	nd (1)	nd (2)	nd (1)	nd (2)	nd (1.6)
1,2,3,7,8-PeCDF	nd (1)	nd (1)	nd (3)	nd (5)	nd (0.9)
2,3,4,7,8-PeCDF	nd (1)	nd (1)	nd (3)	nd (5)	nd (0.9)
1,2,3,4,7,8-HxCDF	35	nd (860)	nd (4)	5,600	nd (20)
1,2,3,6,7,8-HxCDF	nd (5)	nd (860)	nd (4)	nd (600)	nd (20)
1,2,3,7,8,9-HxCDF	6	nd (680)	nd (4)	nd (600)	nd (20)
2,3,4,6,7,8-HxCDF	nd (5)	nd (680)	nd (4)	nd (600)	nd (20)
1,2,3,4,6,7,8-HpCDF	33	240,000	36	230,000	15,000
1,2,3,4,7,8,9-HpCDF	nd (15)	nd (100)	nd (15)	nd (400)	nd (20)
OCDF	18,000	200,000	50,000	110,000	59,000
TOTAL TEQ	263	2,874	814	3,065	211

Source: Cash (1993)

nd = not detected at the minimum limit of detection shown in parenthesis.

substance. Total TBDD, TBDF, and PeBDF were found at 84 μg/kg, 12 μg/kg, and 1 μg/kg, respectively. No hexa-, hepta-, or octa-BDFs were detected. Thoma and Hutzinger (1989) also analyzed analytical grade samples of two other brominated flame retardants, pentabromophenol and tetrabromophthalic anhydride; no BDDs or BDFs were detected (detection limits not reported).

3.4.3. Manufacture of Halogenated Organic Chemicals-Pesticide Data Call-In

In the early 1980s, attention began to focus on pesticides as potential sources of CDDs and CDFs in the environment. Historically, no regulation had been placed on CDD and CDF levels in end-use pesticide products. Certain pesticide active ingredients were known or suspected, however, to be contaminated with CDDs and CDFs (e.g., pentachlorophenol (PCP), Silvex, and 2,4,5-T). During the mid and late 1980s, EPA took several actions to investigate and control CDD/CDF contamination of pesticides. In 1983, the sale of Silvex and 2,4,5-T was canceled for all uses by EPA (Federal Register, October 18, 1983). EPA entered into a Settlement Agreement in 1987 with PCP manufacturers to allow continued registrations for wood uses (Federal Register, January 2, 1987) but which set tolerance levels for HxCDD and 2,3,7,8-TCDD. TCDD levels were not allowed to exceed 1.0 ppb in any product, and after February 2, 1989 (a gradually phased in requirement), any manufacturing-use PCP released for shipment could not contain HxCDD levels that exceeded an average of 2 ppm over a monthly release or a batch level of 4 ppm. EPA then issued a Final Determination and Intent to Cancel and Deny Applications For Registrations of Pesticide Products Containing Pentachlorophenol (Including but not limited to its salts and esters) For Non-Wood Uses which prohibited the registration of PCP for nonwood uses (Federal Register, January 21, 1987).

In addition to these cancellations and product standards, EPA's Office of Pesticide Programs (OPP) issued two Data Call-Ins (DCIs) in June 1987. Pesticide manufacturers are required to register their products with EPA in order to market them commercially in the United States. Through the registration process, mandated by FIFRA (Federal Insecticide, Fungicide and Rodenticide Act), EPA can require that the manufacturer of each active ingredient generate a wide variety of scientific data through several mechanisms.

The most common process is the five phase reregistration effort to which the manufacturers (i.e., registrants) of older pesticide products must comply. In most registration activities, registrants must generate data under a series of strict testing guidelines, 40 CFR 158--Pesticide Assessment Guidelines (U.S.EPA, 1988). FIFRA accommodates the fact that some pesticide active ingredients may require additional data, outside of the norm, to adequately develop effective regulatory policies for those products. Therefore, EPA can require additional data, where needed, through various mechanisms as noted above including the DCI process.

The purpose of the first DCI (June 6, 1987), Data Call In Notice For Product Chemistry Relating to Potential Formation of Halogenated Dibenzo-p-dioxin or Dibenzofuran Contaminants in Certain Active Ingredients, was to identify chemicals that may contain halogenated dibenzo-p-dioxin and dibenzofuran contaminants and to quantify and eventually minimize exposure to these contaminants. The requirements made in this DCI parallel requirements established in the Dioxin/Furan Test Rule promulgated under Sections 4 and 8 of TSCA. (See Section 3.4.2.) The list of pesticide active ingredients to which this DCI applied along with their corresponding Shaughnessey and Chemical Abstract code numbers are presented in Table 3-15. [Note: the Shaughnessey code is an internal EPA tracking system--it is of interest because chemicals with similar code numbers are similar in chemical nature (e.g., salts, esters and acid forms of 2,4-D)]. All registrants supporting these chemicals were subject to the requirements of this DCI unless their product qualified for a Generic Data Exemption (i.e., a registrant exclusively used a registered product(s) as the source(s) of the active ingredient(s) identified in Table 3-15 in formulating their product(s)). Registrants whose products did not meet the Generic Data Exemption were required to submit the types of data listed below to assess the formation of tetra- through hepta-halogenated dibenzo-p-dioxin or dibenzofuran contaminants during manufacture. Registrants, however, did have the option to voluntarily cancel their product or "reformulate to remove an active ingredient," described in Table 3-15, to avoid compliance with the DCI.

Table 3-15. Pesticides That Could Become Contaminated With Dioxins If Synthesized Under Conditions Which Favor Dioxin Formation

Shaughnessey Code	Pesticide (Active Ingredient)	CAS Number
008706	O-(4-Bromo-2,5-dichlorophenyl) O,O-dimethyl phosphorothioate	2104-96-3
009105	Dimethylamine 2,3,5-triiodobenzoate	17601-49-9
012001	Neburon	555-37-3
012101	Crufomate	299-86-5
019201	4-(2-Methyl-4-chlorophenoxy)butyric acid	94-81-5
019202	Sodium 4-(2-methyl-4-chlorophenoxy)butyrate	6062-26-6
019401	4-Chlorophenoxyacetic acid	122-88-3
025501	Chloroxuron	1982-47-4
027401	Dichlobenil	1194-65-6
028201	3',4'-Dichloropropionanilide	709-98-8
028601	Dichlofenthion (O-(2,4-Dichlorophenyl) O,O-diethyl phosphorothioate)	97-17-6
029201	Dichloro diphenyl trichloroethane	50-29-3
029601	Dichlone (2,3-dichloro-1,4-naphthoquinone)	117-80-6
029902	Ammonium chloramben (3-amino-2,5-dichlorobenzoic acid)	1076-46-6
029906	Sodium chloramben (3-amino-2,5-dichlorobenzoic acid)	1954-81-0
030602	Sodium 2-(2,4-dichlorophenoxy)ethyl sulfate	136-78-7
031301	2,6-Dichloro-4-nitroaniline	99-30-9
031501	2-(2-Methyl-4-chlorophenoxy)propionic acid	7085-19-0
031503	Potassium 2-(2-methyl-4-chlorophenoxy)propionate	1929-86-8
031516	Diethanolamine 2-(2-methyl-4-chlorophenoxy)propionate	1432-14-0
031519	Dimethylamine 2-(2-methyl-4-chlorophenoxy)propionate	32351-70-5
031563	Isooctyl 2-(2-methyl-4-chlorophenoxy)propionate	28473-03-2

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Table 3-15. Pesticides That Could Become Contaminated With Dioxins If Synthesized Under Conditions Which Favor Dioxin Formation (continued)

Shaughnessey Code	Pesticide (Active Ingredient)	CAS Number
034502	Dicapthon (O-(2-chloro-4-nitrophenyl) O,O-dimethyl phosphorothioate)	2463-84-5
035502	Monuron trichloroacetate (3-(4-chlorophenyl)-1,1-dimethylurea trichloroacetate)	140-41-0
035505	Diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea)	330-54-1
035506	Linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea)	330-55-2
035901	Metobromuron (3-(p-bromophenyl)-1-methoxy-1-methylurea)	3060-89-7
053501	O,O-Dimethyl O-p-nitrophenyl phosphorothioate	298-00-0
054901	5-Chloro-2-(2,4-dichlorophenoxy)phenol	3380-34-5
055001	Dichlorophene	97-23-4
055005	Sodium 2,2'-methylenebis(4-chlorophenate)	10254-48-5
055201	1,2,4,5-Tetrachloro-3-nitrobenzene	117-18-0
057501	Parathion (O,O-diethyl O-p-nitrophenyl phosphorothioate)	56-38-2
058102	Carbophenothion (S-(((p-chlorophenyl)thio)methyl) O,O-diethyl phosphorodithioate)	786-19-6
058301	Ronnel (O,O-dimethyl O-(2,4,5-trichlorophenyl) phosphorothioate)	229-84-3
058802	Sodium 5-chloro-2-(4-chloro-2-(3-(3,4-dichlorophenyl)ureido)phenoxy) benzenesulfonate	3567-25-7
059401	Orthodichlorobenzene	95-50-1
061501	Paradichlorobenzene	106-46-7
062201	2-Benzyl-4-chlorophenol	120-32-1
062202	Potassium 2-benzyl-4-chlorophenate	35471-49-9
062203	Sodium 2-benzyl-4-chlorophenate	3184-65-4
062204	2-Chlorophenol	95-57-8
062206	2-Chloro-4-phenylphenol	92-04-6

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Table 3-15. Pesticides That Could Become Contaminated With Dioxins If Synthesized Under Conditions Which Favor Dioxin Formation (continued)

Shaughnessey Code	Pesticide (Active Ingredient)	CAS Number
062207	Potassium 2-chloro-4-phenylphenate	18128-16-0
062208	4-Chloro-2-phenylphenol	not available from Source
062209	4-Chloro-2-phenylphenol, potassium salt	53404-21-0
062210	6-Chloro-2-phenylphenol	85-97-2
062211	6-Chloro-2-phenylphenol, potassium salt	18128-17-1
062212	4-Chloro-2-phenylphenol, sodium salt	10605-10-4
062213	6-Chloro-2-phenylphenol, sodium salt	10605-11-5
062214	4 and 6-Chloro-2-phenylphenol, diethanolamine salt	53537-63-6
062215	2-Chloro-4-phenylphenol, sodium salt	31366-97-9
064202	4-Chloro-2-cyclopentylphenol	13347-42-7
064208	2,2'-Thiobis(4-chloro-6-methylphenol)	4418-66-0
064209	2,2'-Thiobis(4-chlorophenol)	97-24-5
064214	4-Chloro-2-cyclopentylphenol, potassium salt of	35471-38-6
064218	4-Chloro-2-cyclopentylphenol, sodium salt	53404-20-9
067707	Chlorophacinone	3691-35-8
069105	Alkyl* dimethyl benzyl ammonium chloride *(50% C14, 40% C12, 10% C16)	68424-85-1
069144	Alkyl* dimethyl 3,4-dichlorobenzyl ammonium chloride *(61% C12, 23% C14, 11% C16, 5% C18)	not avilable from Source
077401	2-Aminoethanol salt of 2',5-dichloro-4'-nitrosalicylanilide	1420-04-8
077406	5-Chlorosalicylanilide	4638-48-6
079202	Tetradifon (4-chlorophenyl 2,4,5-trichlorophenyl sulfone)	116-29-0
079301	Chloranil (tetrachloro-p-benzoquinone)	118-75-2
079401	Endosulfan (hexachlorohexahydromethano-2,4,3-benzodioxathiepin-3-oxide)	115-29-7

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Table 3-15. Pesticides That Could Become Contaminated With Dioxins If Synthesized Under Conditions Which Favor Dioxin Formation (continued)

Shaughnessey Code	Pesticide (Active Ingredient)	CAS Number
080403	6-Chlorothymol	89-68-9
080811	2,4-Dichloro-6-(o-chloroanilino)-s-triazine	101-05-3
081901	Chlorothalonil (tetrachloroisophthalonitrile)	1897-45-6
084101	Chlorfenvinphos	470-90-6
084901	O-(2-Chloro-1-(2,5-dichlorophenyl)vinyl) O,O-diethyl phosphorothioate	1757-18-2
086801	4-Chloro-3,5-xylenol	88-04-0
097003	3-(2-Methylpiperidino)propyl 3,4-dichlorobenzoate	3478-94-2
101001	p-Chlorophenyl diiodomethyl sulfone	20018-12-6
101101	Metribuzin	21087-64-9
104301	Bifenox (methyl 5-(2,4-dichlorophenoxy)-2-nitrobenzoate)	42576-02-3
106001	Methazole (2-(3,4-dichlorophenyl)-4-methyl-1,2,4-oxadiazolidine-3,5-dione)	20354-26-1
108201	Diflubenzuron (N-(((4-chlorophenyl)amino)carbonyl)-2,6-difluorobenzamide)	35367-38-5
109001	Oxadiazon (2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)- delta 2 -1,3,4- oxadiazoline-5-one)	19666-30-9
109301	Fenvalerate	51630-58-1
109302	N-¿2-Chloro-4-trifluoromethyl)phenyl¿-DL-valine (+-)-cyano(3-phenoxy-phenyl)methyl ester	69409-94-5
109801	3-(3,5-Dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide (9CA)	36734-19-7
109901	1-(4-Chlorophenoxy)-3,3-dimethyl-1-(1H-1,2,4-triazol-1-yl)-2-butanone	43121-43-3
110902	Diclofop - methyl (methyl 2-(4-(2,4-dichlorophenoxy)phenoxy)propanoate)	51338-27-3
111401	O-(4-Bromo-2-chlorophenyl)-O-ethyl S-propyl phosphorothioate	41198-08-7
111601	Oxyfluorfen (2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene)	42874-03-3
111901	1-(2-(2,4-Dichlorophenyl)-2-(2-propenyloxy)ethyl)-1H-imidazole	35554-44-0

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Table 3-15. Pesticides That Could Become Contaminated With Dioxins If Synthesized Under Conditions Which Favor Dioxin Formation (continued)

Shaughnessey Code	Pesticide (Active Ingredient)	CAS Number
112802	N-Methyl-2,4-dinitro-n-(2,4,6-tribromophenyl)-6-(trifuloromethyl)benzenamine	63333-35-7
113201	3-(3,5-Dichlorophenyl)-5-ethenyl-5-methyl-2,4-oxazolidinedione (9CA)	50471-44-8
119001	Potassium 1-(p-chlorophenyl)-1,4-dihydro-6-methyl-4-oxo- pyridazine-3-carboxylate	83588-43-6
123901	2-(3,5-Dichlorophenyl)-2-(2,2,2-trichloroethyl) oxirane	58138-08-2
125601	Paclobutrazol	76738-62-0
128838	Linalool	78-70-6
206600	Fenarimol (a-(2-chlorophenyl)-a-(4-chlorophenyl)-5-pyrimidinemethanol)	60168-88-9

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- Product Identity and Disclosure of Ingredients: EPA required submittal of a Confidential Statement of Formula (CSF) based on the requirements specified in 40 CFR 158.108 and 40 CFR 158.120 - Subdivision D:Product Chemistry. Registrants who had previously submitted still current CSFs were not required to resubmit this information.

- Description of Beginning Materials and Manufacturing Process: Based on the requirements mandated by 40 CFR 158.120 - Subdivision D, EPA required submittal of a manufacturing process description for each step of the manufacturing process, including specification of the range of acceptable conditions of temperature, pressure, or pH at each step.

- Discussion of the Formation of Impurities: Based on the requirements mandated by 40 CFR 158.120 - Subdivision D, EPA required submittal of a detailed discussion/assessment of the possible formation of halogenated dibenzo-p-dioxins and dibenzofurans.

The second DCI (dated June 15, 1987), Data Call-In For Analytical Chemistry Data on Polyhalogenated Dibenzo-p-Dioxins/Dibenzofurans (HDDs and HDFs), was issued for a variety of pesticide active ingredients to the individual manufacturers of each ingredient. (See Table 3-16.) All registrants supporting these pesticides were subject to the requirements of this DCI unless the product qualified for various exemptions or waivers. Pesticides regulated by the second DCI were strongly suspected to be contaminated with detectable levels of HDDs/HDFs.

Under the second DCI, registrants whose products did not qualify for an exemption or waiver were required to generate and submit the following types of data in addition to the data requirements of the first DCI:

Table 3-16. Pesticides That Are Suspected To Be Contaminated With Dioxins

Shaughnessy Code	Pesticide (Active Ingredient)	CAS Number
029801	Dicamba (3,6-dichloro-o-anisic acid)	1918-00-9
029802	Dimethylamine dicamba (3,6-dichloro-o-anisic acid)	2300-66-5
029803	Diethanolamine dicamba (3,6-dichloro-2-anisic acid)	25059-78-3
030001	2,4-Dichlorophenoxyacetic acid	94-75-7
030002	Lithium 2,4-dichlorophenoxyacetate	3766-27-6
030003	Potassium 2,4-dichlorophenoxyacetate	14214-89-2
030004	Sodium 2,4-dichlorophenoxyacetate	2702-72-9
030005	Ammonium 2,4-dichlorophenoxyacetate	2307-55-3
030010	Alkanol* amine 2,4-dichlorophenoxyacetate *(salts of the ethanol and ispropanol series)	not available from Source
030011	Alkyl* amine 2,4-dichlorophenoxyacetate *(100% C12)	2212-54-6
030013	Alkyl* amine 2,4-dichlorophenoxyacetate *(100% C14)	28685-18-9
030014	Alkyl* amine 2,4-dichlorophenoxyacetate *(as in fatty acids of tall oil)	not available from Source
030016	Diethanolamine 2,4-dichlorophenoxyacetate	5742-19-8
030017	Diethylamine 2,4-dichlorophenoxyacetate	20940-37-8
030019	Dimethylamine 2,4-dichlorophenoxyacetate	2008-39-1
030020	N,N-Dimethyloleylamine 2,4-dichlorophenoxyacetate	53535-36-7
030021	Ethanolamine 2,4-dichlorophenoxyacetate	3599-58-4
030023	Heptylamine 2,4-dichlorophenoxyacetate	37102-63-9
030024	Isopropanolamine 2,4-dichlorophenoxyacetate	6365-72-6
030025	Isopropylamine 2,4-dichlorophenoxyacetate	5742-17-6
030028	Morpholine 2,4-dichlorophenoxyacetate	6365-73-7
030029	N-Oleyl-1,3-propylenediamine 2,4-dichlorophenoxyacetate	2212-59-1
030030	Octylamine 2,4-dichlorophenoxyacetate	2212-53-5

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Table 3-16. Pesticides That Are Suspected To Be Contaminated With Dioxins (continued)

Shaughnessy Code	Pesticide (Active Ingredient)	CAS Number
030033	Triethanolamine 2,4-dichlorophenoxyacetate	2569-01-9
030034	Triethylamine 2,4-dichlorophenoxyacetate	2646-78-8
030035	Triisopropanolamine 2,4-dichlorophenoxyacetate	32341-80-3
030039	N,N-Dimethyl oleyl-linoleyl amine 2,4-dichlorophenoxyacetate	55256-32-1
030052	Butoxyethoxypropyl 2,4-dichlorophenoxyacetate	1928-57-0
030053	Butoxyethyl 2,4-dichlorophenoxyacetate	1929-73-3
030055	Butoxypropyl 2,4-dichlorophenoxyacetate	1928-45-6
030056	Butyl 2,4-dichlorophenoxyacetate	94-80-4
030062	Isobutyl 2,4-dichlorophenoxyacetate	1713-15-1
030063	Isooctyl(2-ethylhexyl) 2,4-dichlorophenoxyacetate	1928-43-4
030064	Isooctyl(2-ethyl-4-methylpentyl) 2,4-dichlorophenoxyacetate	25168-26-7
030065	Isooctyl(2-octyl) 2,4-dichlorophenoxyacetate	1917-97-1
030066	Isopropyl 2,4-dichlorophenoxyacetate	94-11-1
030072	Propylene glycol butyl ether 2,4-dichlorophenoxyacetate	1320-18-9
030801	4-(2,4-Dichlorophenoxy)butyric acid	94-82-6
030804	Sodium 4-(2,4-dichlorophenoxy)butyrate	10433-59-7
030819	Dimethylamine 4-(2,4-dichlorophenoxy)butyrate	2758-42-1
030853	Butoxyethanol 4-(2,4-dichlorophenoxy)butyrate	32357-46-3
030856	Butyl 4-(2,4-dichlorophenoxy)butyrate	6753-24-8
030863	Isooctyl 4-(2,4-dichlorophenoxy)butyrate	1320-15-6
031401	2-(2,4-Dichlorophenoxy)propionic acid	120-36-5
031419	Dimethylamine 2-(2,4-dichlorophenoxy)propionate	53404-32-3
031453	Butoxyethyl 2-(2,4-dichlorophenoxy)propionate	53404-31-2
031463	Isooctyl 2-(2,4-dichlorophenoxy)propionate	28631-35-8

DRAFT--DO NOT QUOTE OR CITE

Table 3-16. Pesticides That Are Suspected To Be Contaminated With Dioxins (continued)

Shaughnessy Code	Pesticide (Active Ingredient)	CAS Number
031501	2-(2-Methyl-4-chlorophenoxy)propionic acid	7085-19-0
031519	Dimethylamine 2-(2-methyl-4-chlorophenoxy)propionate	32351-70-5
035301	Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile)	1689-84-5
044901	2,2′-Methylenebis(3,4,6-trichlorophenol)	70-30-4
044902	Monosodium 2,2′-methylenebis(3,4,6-trichlorophenate)	5736-15-2
044904	Potassium 2,2′-methylenebis(3,4,6-trichlorophenate)	67923-62-0
054901	5-Chloro-2-(2,4-dichlorophenoxy)phenol	3380-34-5
063004	Tetrachlorophenols	25167-83-3
063005	Tetrachlorophenols, sodium salt	25567-55-9
063006	Tetrachlorophenols, alkyl* amine salt*(as in fatty acids of coconut oil)	not available from Source
063007	Tetrachlorophenols, potassium salt	53535-27-6
064203	Disodium 2,2′-thiobis(4,6-dichlorophenate)	6385-58-6
064212	2,4,6-Trichlorophenol	88-06-2
064219	Potassium 2,4,6-trichlorophenate	2591-21-1
064220	2,4,6-Trichlorophenol, sodium salt	3784-03-0
064501	Phenothiazine	92-84-2
078701	Dimethyl tetrachloroterephthalate	1861-32-1
079401	Endosulfan (hexachlorohexahydromethano-2,4,3-benzodioxathiepin-3-oxide)	115-29-7
082501	Silvex (2-(2,4,5-trichlorophenoxy)propionic acid)	93-72-1
083701	2-Chloro-1-(2,4,5-trichlorophenyl)vinyl dimethyl phosphate	961-11-5
104101	Sodium 1,4′,5′-trichloro-2′-(2,4,5-trichlorophenoxy)methanesulfonanilide	69462-14-2

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- Quantitative Method For Measuring HDDs or HDFs: Registrants were required to develop an analytical method for assessing the HDD/HDF contamination of their products. The DCI established a regimen for defining the precision of the analytical method (i.e., for internal standard--precision within +/- 20 percent and recovery range of 50 to 150 percent, also a signal to noise ratio of at least 10:1 was required). Target quantification limits were established in the DCI for specific HDD and HDF congeners. (See Table 3-11.)

- Certification of Limits of HDDs or HDFs: Registrants were required to submit a "Certification of Limits" in accordance with 40 CFR 158.110 and 40 CFR 158.120 - Subdivision D. Analytical results were required that met the guidelines described above.

Registrants could select one of two options to comply with the second DCI. The first option was to submit relevant existing data, develop new data, or share the cost to develop new data with other registrants. The second option was to alleviate the DCI requirements through several exemption processes including a Generic Data Exemption, voluntary cancellation, reformulation to remove the active ingredient of concern, an assertion that the data requirements do not apply, or the application/award of a low-volume, minor-use waiver.

The data contained in CSFs, as well as any other data generated under Subdivision D, are typically considered Confidential Business Information (CBI) under the guidelines prescribed in FIFRA because they usually contain information regarding proprietary manufacturing processes. In general, all analytical results submitted to EPA in response to both DCIs are considered CBI and cannot be released by EPA into the public domain. Summaries based on the trends identified in that data as well as data made public by EPA are provided below.

To date, more than 100 submissions have been reviewed in response to the two DCIs. The majority have been manufacturing process data in support of waiver requests,

analytical method protocols, and sample collection protocols (telephone conversation between S. Funk, EPA - Office of Pesticide Programs (OPP), and J. Dawson, Versar, Inc. on 2/18/93). Analytical results on the levels of tetra- through hepta- HDDs/HDFs have been received and reviewed for 16 distinct pesticide active ingredients (Table 3-17). In general, the analyses have not revealed HDD/HDF concentrations in excess of the LOQs specified in Table 3-11. For those products in which LOQs are exceeded, the identified contamination levels were generally within an order of magnitude of the LOQ and apply only to one or two congeners per product (telephone conversation between S. Funk, EPA/

OPP, and J. Dawson, Versar, Inc. on 2/18/93). Table 3-18 presents a summary of results recently reported by EPA for CDDs and CDFs in eight technical 2,4-D herbicides.

3.4.4. Chlorine Production Using Graphite Electrodes

The production and use of chlorine gas has involved processes that result in the generation of CDFs (Rappe, 1992a). Chlorine is commonly produced via electrolysis of brine in mercury cells. High levels of CDFs have been found in the graphite electrode sludge from this chemical process and may have been responsible for occupational exposures among workers who handled these sludges. Svensson et al. (1992) evaluated the relationship between blood CDF levels in chloralkali plant workers and direct exposure of these workers to electrode sludges and to dust and earth contaminated with graphite electrode sludge. Subjects who had been exposed by handling graphite electrode sludge had higher levels of 2,3,7,8-substituted PeCDFs and HxCDFs than reference subjects. Evaluations of congener distribution patterns have demonstrated that the 2,3,7,8-substituted CDFs are the major congeners formed during the chloralkali process (Rappe et al., 1990; Rappe, 1992a).

Until the late 1970s, graphite electrodes were the primary type of anode used in the chloralkali industry (Curlin and Bommaraju, 1991). Since then, metal anodes have been developed to replace graphite electrodes because of production problems associated with their use (U.S. EPA, 1982; Curlin and Bommaraju, 1991). Currently, no U.S. facilities are believed to use graphite electrodes in the production of chlorine gas (telephone

Table 3-17. Summary of Analytical Data Submitted to-Date in Response to Pesticide Data Call-In

Pesticide (Active Ingredient)	No. of Reviews Submitted[a]
1,2-Benzisothiazolin-3-one	1
2,4-D[b]	15
Atrazine	2
Bromoxynil	1
Chlorothalonil	1
Dacthal (DCPA)	1
Dicamba	1
Diclofop-Methyl	1
Diflubenzuron	1
Linuron	1
MCPA[c]	3
MCPB	1
MCPP (Mecoprop)	2
MCPP-$_p$	1
Tetrachlorvinphos	2
Toclofos-Methyl	1

a Indicates number of submissions containing analytical data that have been reviewed as of 2/18/93 in support of each active ingredient (Personal communication - Jeff Dawson, Versar, with Steve Funk, EPA/OPP/HED/CBRS on February 18, 1993; Schmitt, 1993; Funk, 1994).

b Includes all submissions for 2,4-D, 2,4-D esters, 2,4-DB, and 2,4-DP.

c Includes submissions for MCPA-Ethylhexyl ester.

Table 3-18. Summary of Results for CDDs and CDFs in Technical 2,4-D Herbicides

Congener	EPA LOQ[a] (ppb)	2,4-D		
		Total Number of Technicals	Number of Technicals Greater Than LOQ	Observed Maximum Concentration (ppb)
2,3,7,8-TCDD	0.1	8	2	0.13[b]
1,2,3,7,8-PeCDD	0.5	8	3	2.6[c]
1,2,3,4,7,8-HxCDD	2.5	8	0	0.81
1,2,3,6,7,8-HxCDD	2.5	8	0	0.77
1,2,3,7,8,9-HxCDD	2.5	8	0	0.68
1,2,3,4,6,7,8-HpCDD	100	8	0	1.5
2,3,7,8-TCDF	1	8	0	0.27
1,2,3,7,8-PeCDF	5	8	0	0.62
2,3,4,7,8-PeCDF	5	7	0	0.73
1,2,3,4,7,8-HxCDF	25	8	0	1.6
1,2,3,6,7,8-HxCDF	25	8	0	1.2
1,2,3,7,8,9-HxCDF	25	8	0	1.4
2,3,4,6,7,8-HxCDF	25	8	0	1.1
1,2,3,4,6,7,8-HpCDF	1000	8	0	8.3
1,2,3,4,7,8,9-HpCDF	1000	8	0	1.2

Source: Schmitt (1993)

[a]Limit of quantitation required by the Agency.

[b]Average 0.07 ppb, where 50 percent of demonstrated LOQ used for analytes not found.

[c]Average 0.63 ppb, where 50 percent of demonstrated LOQ used for analytes not found.

conversation between L. Phillips, Versar, Inc., and T. Fielding, U.S. EPA, Office of Water, February 1993). Although the use of graphite electrodes has been eliminated, the potential for CDD/CDF releases from dump sites containing contaminated sludges may still exist (Svensson et al., 1992; Rappe, 1992a).

3.4.5. Petroleum Refining Catalyst Regeneration

Catalyst regeneration in the petroleum refinery reforming process has been identified as a source of CDDs and CDFs based on testing conducted in Canada (Thompson et al., 1990). According to Thompson et al. (1990), "catalytic reforming is a refinery process which is used to produce high octane gasoline. The reforming process occurs at high temperature and pressure and requires the use of a catalyst. During the catalytic process, a complex mixture of aromatic compounds known as coke is formed and deposited onto the catalyst. As coke deposits onto the catalyst, its activity is decreased. The high cost of the catalyst necessitates its regeneration. Catalyst regeneration is achieved by removing the coke deposits via burning and activating the catalyst using chlorinated compounds. Burning of the coke produces flue gases which contain CDDs and CDFs along with other combustion products." Thompson et al. (1990) reported total CDD and CDF concentrations of 8.9 ng/m^3 and 210 ng/m^3, respectively, in stack gas samples from petroleum refinery reforming operations (Table 3-19). It was also found that the CDD and CDF congener distribution patterns observed were similar to those found in municipal waste incinerator ash and stack samples. Because flue gases may be scrubbed with water, internal effluents may also be contaminated with CDD/CDFs. Thompson et al. (1990) observed CDDs and CDFs in the internal wash water from a scrubber of a periodic/cyclic regenerator (Table 3-20).

The Canadian Ministry of the Environment detected concentrations of CDDs in an internal wastestream of spent caustic in a petroleum refinery that ranged from 1.8 to 22.2 ppb, and CDFs ranging from 4.4 to 27.6 ppb. The highest concentration of 2,3,7,8-TCDD was 0.0054 ppb (Maniff and Lewis, 1988). CDDs were also observed in the refinery's biological sludge at a maximum concentration of 74.5 ppb, and CDFs were observed at a

Table 3-19. CDDs/CDFs in Petroleum Refinery Stack Gas from a Continuous Regenerator Without Scrubber

Congener Group	Concentration[a] ($\mu g/m^3$)	
	CDDs	PCDFs
TCD	1.6 (7)	46 (11)
PeCD	3.4 (8)	120 (10)
HxCD	1.9 (4)	31 (9)
HpCD	1.2 (2)	12 (4)
OCD	0.8	1.7
TOTAL	**8.9**	**210**

[a] Values represent average concentrations for three tests. Numbers in brackets indicate number of isomers detected.

Source: Thompson et al. (1990).

Table 3-20. CDDs/CDFs in the Scrubber Wash Water from a Petroleum Refinery Periodic/Cyclic Regenerator

Congener Group	No. of Positive[a] Occurences	Concentration Range[b] (ppq)		No. of Congeners	
		Low	High	Low	High
TCDD	7	44	110	7	11
PeCDD	7	15	90	2	13
HxCDD	6	ND(17)	160	0	6
HpCDD	1	ND(20)	64	0	2
OCDD	1	ND(22)	56	0	1
TCDF	7	150	660	14	14
PeCDF	7	40	330	5	10
HxCDF	7	20	260	3	12
HpCDF	7	10	160	1	4
OCDF	7	23	93	1	1

[a] Number of positive occurences based on seven samples analyzed.
[b] Numbers in parentheses are detection limits.

Source: Thompson et al. (1990).

maximum concentration of 125 ppb (Maniff and Lewis, 1988). The concentration of CDD/CDFs in the final combined refinery plant effluent was below the detection limits.

Insufficient data are available to evaluate CDD/CDF releases from these sources in the United States. However, Beard et al. (1993) conducted a series of benchtop experiments to investigate the mechanism(s) of CDD/CDF formation in the catalytic reforming process. A possible pathway for the formation of CDFs was found, but the results could not explain the formation of CDDs. Analyses of the flue gas from burning coked catalysts revealed the presence of unchlorinated dibenzofuran (DBF) produced in quantities of up to 220 ng/g of catalyst. Chlorination experiments indicated that dibenzofuran and possibly biphenyl and similar hydrocarbons act as CDF precursors and can become chlorinated in the catalyst regeneration process. Corrosion products on the steel piping of the process plant seem to be the most likely chlorinating agent. Furthermore, CDFs can form by *de novo* synthesis from chlorinated hydrocarbons like trichloroethylene, methylene chloride, and carbon tetrachloride in the presence of $FeCl_3$ and HCl or Cl_2.

3.4.6. Additional Chemical Manufacturing and Processing Sources

Rappe et al. (1989) reported the formation of CDFs (tetra- through octa-chlorinated CDFs) when tap water and double-distilled water were chlorinated using chlorine gas. The CDF levels found in the single samples of tap water and double-distilled water were 35 and 7 pg TEQ/L, respectively. The water samples were chlorinated at a dosage rate of 300 mg of chlorine per liter of water which is considerably higher (by a factor of one to two orders of magnitude) than the range of dosage rates typically used to disinfect drinking water. Rappe et al. (1989) hypothesized that the CDFs or their precursors are present in chlorine gas. It should be noted, however, that although few surveys of finished drinking water for CDD/CDF levels have been conducted, the few that have been published only rarely report the presence of any CDD/CDF even at low pg/L detection limits and in those cases the CDD/CDFs were also present in the untreated water. (See Section 4.3.)

Several recent studies have been conducted to identify the source(s) of CDD/CDFs found in textiles and at dry cleaning facilities. Horstmann and McLachlan (1994) analyzed 35 new textiles and found total CDD/CDF levels generally less than 50 pg/g; however, some items were as high as 290,000 pg/g. The authors conclude that textile finishing processes are not likely to be the source of the high CDD/CDF levels found because of the apparent randomness of the textiles with high CDD/CDF levels. However, the authors hypothesize that the use of pentachlorophenol to preserve cotton, particularly when it is randomly strewed on bales of cotton as a preservative during sea transport, is the likely source of the high levels occasionally observed. As discussed in Section 3.4.3, the use of pentachlorophenol (PCP) for nonwood uses has been prohibited in the United States since 1987. However, Horstmann and McLachlan (1994) comment that PCP is still used in developing countries, especially for purposes of preserving cotton during sea transport. As discussed in Section 3.4.1.5, certain dyes and pigments have also been observed to contain CDD/CDFs and may also contribute to levels found in textiles. Horstmann and McLachlan (1994) also summarize recent research concerning CDD/CDFs in dry cleaning residues and reach the conclusion that new textiles are the source of the CDD/CDFs found.

3.5. MECHANISMS OF FORMATION OF DIOXIN-LIKE COMPOUNDS DURING COMBUSTION OF ORGANIC MATERIALS

The specific molecular mechanisms by which CDDs and CDFs are initially formed and then emitted from combustion sources remain largely unknown and are theoretical. The theoretical basis for conjecture is derived primarily from direct observations in municipal solid waste incinerators and from well conducted laboratory studies. Municipal solid waste incinerators (MSWIs) have been heavily studied from the perspective of eventually finding the specific formation mechanism transpiring within the system, and determining ways to either significantly reduce such opportunities or ultimately hinder the formation kinetics to preclude evolution of these chemicals. Although much has been learned from these studies, it is still not known how to completely block the formation of CDDs/CDFs during the combustion of certain organic materials in the presence of a source

of chlorine. Adding to this complexity is the wide variability of organic materials that are incinerated and thermally processed by a wide spectrum of combustion technologies having variable temperatures, residence times, and oxygen requirements. However, it is possible to identify the central chemical events participating in the formation of CDDs and CDFs by evaluating emission test results from MSWIs in combination with laboratory experiments.

The emission of CDDs and CDFs can be explained by three principal theories, which should not be regarded as being mutually exclusive. The first is that CDD/CDFs are present as contaminants in the combusted organic material. This theory is discussed in Section 3.5.1. The second is that CDDs/CDFs are ultimately formed from the thermal breakdown and molecular rearrangement of precursor compounds, which are defined as chlorinated aromatic hydrocarbons having a structural resemblance to the CDD/CDF molecule. This theory is discussed in Section 3.5.2. The third theory, similar to the second and described in Section 3.5.3, is that CDDs/CDFs are synthesized *de novo*; this means they are formed from organic and inorganic substrates comprised of singular or mixtures of molecules bearing little resemblance to the molecular structure of CDDs or CDFs. Section 3.5.4 discusses the generation of coplanar PCBs. Section 3.5.5 discusses the evaluation of naturally occurring CDDs/CDFs by examinations of sediment core data, and Section 3.5.6 provides a closing summary of the three principal theories of formation.

3.5.1. CDD/CDF Contamination in Fuel as a Source of Combustion Stack Emissions

The first theory states that CDD and CDF compounds present as contaminants in the fuel or waste products that are fed into the combustion chamber are responsible for dioxin and dibenzofuran emissions out the stack of the combustion process. Most work in this area has involved the study of municipal solid waste incineration (MSWI) in which case CDDs and CDFs have been analytically detected in the raw refuse fed into the MSWI. Tosine, et al. (1983) first reported detecting trace amounts of HpCDD and OCDD in the MSW fed into an MSWI in Canada. HpCDD ranged in concentration from 100 ppt to 1 ppb, and OCDD ranged from 400 to 600 ppt. Wilken et al. (1992) separated the various solid waste fractions of MSW collected from municipalities in Germany and analyzed them

for the presence of CDDs/CDFs and other organochlorine compounds. Total CDDs/CDFs were detected in all MSW fractions in the following range of concentrations: paper and cardboard = 3.1 to 45.5 ppb; plastics, wood, leather, textiles combined = 9.5 to 109.2 ppb; vegetable matter = 0.9 to 16.9 ppb; and "fine debris" (defined as particles < 8 mm) = 0.8 to 83.8 ppb. Ozvacic (1985) measured CDDs/CDFs in the raw MSW fed into two MSWIs operating in Canada. In one MSWI, CDDs were detected in the refuse in a range of concentration from 10 to 30 ppb, but no CDFs were detected (detection limit: 1 pg/g). In the MSW fed to the second MSWI, CDDs were detected in a range of 75 to 439 ppb, and CDFs were detected only in one of three samples at a total concentration of 11 ppb. EPA has reported on the detection of CDDs/CDFs in refuse derived fuel (RDF) burned in a large, urban MSWI (Federal Register, 1991). From 13 MSW samples taken prior to incineration, CDDs were detected in a range of 1 to 13 ppb, and CDFs were measured in a range of 0 to 0.6 ppb. In these samples, OCDD predominated, and the lower chlorinated congeners were not detected.

Despite these findings, the conditions of thermal stress imposed by the incineration process discounts the likelihood that the total magnitude of CDDs and CDFs, as measured in the raw MSW, can explain the total magnitude of concentration as an emission from the stack of the MSWI (Clement et al., 1990; Commoner, 1990). Contamination, however, may partially contribute to the stack release. Clement and coworkers (1988) performed a mass balance involving an input versus output of dioxin at two operational MSWIs in Canada. These mass balance calculations clearly demonstrated that the mass of CDDs and CDFs emitted at the point of the stack was much greater than the mass in the raw MSW incinerated at the MSWIs, and that the profiles of the distributions of CDD/CDF congeners were strikingly different. Primarily, higher chlorinated congeners were detected as contaminants in the waste, whereas the total array of tetra - octa CDDs/CDFs were emitted from the stack.

Commoner and coworkers (1984; 1985; 1987) evaluated the test data of a mass burn MSW incinerator for the concentration of CDDs and CDFs at multiple sampling points during the combustion process: (1) exit to the furnace; (2) entry to the heat exchanger; (3) inlet to the electrostatic precipitator (ESP); (4) exit to the ESP; and (5) exit to the

smokestack. Lowest or nondetectable concentrations of CDDs/CDFs were found at sampling point (1), and highest concentrations were measured at sampling point (5). From these sampling data, Commoner concluded that: CDDs/CDFs were not formed within the furnace region where the waste material was combusted and that usually only OCDD and OCDF were detected in extremely low concentrations at the point of exit to the furnace (if dioxins were detected at all). It was also concluded that the CDDs/CDFs were mostly formed as a synthesis process catalyzed by the properties of fly ash in combination with chlorine, and that this probably transpired within areas downstream of the combustion zone where the combustion offgases had cooled to less than 400°C. Commoner et al. (1984, 1987) ruled out the effectiveness of combustion as a major factor in CDD/CDF emissions from the stack; this would be expected if waste contamination was solely responsible for the emission. This phenomena was independently observed by Environment Canada in a series of tests of a modular MSW incinerator (Hay, et al., 1986; Environment Canada, 1985). On a mass balance basis, the concentration of CDDs and CDFs measured at the stack was approximately two orders of magnitude higher as compared to the inlet to the boiler just after exiting the secondary furnace. The temperatures of the combustion gases at these two points of measurement were 130 and 740°C at the stack and boiler inlet, respectively (Environment Canada, 1985). For the most part, only OCDD was present in the hot gases exiting the furnace, whereas all the congeners were present in the stack emissions, thus giving further evidence that CDDs/CDFs are formed after the combustion zone. Using similar protocols, EPA and Environment Canada (1991) jointly evaluated the emission of CDDs and CDFs from a refuse-derived fuel MSWI operating in the United States. It was found that approximately 5 milligrams of total CDDs and CDFs per metric ton of MSW burned by the facility were measured in the raw MSW prior to combustion, but no CDDs nor CDFs were detected at the point of exit to the furnace prior to the inlet to the economizer (i.e., the heat exchanger used to extract additional heat from the hot gases). Once heat in the combustion gas was extracted for energy purposes and the gases were further cooled to less than 400°C, the total array of tetra- through octa-CDDs and CDFs could be detected.

These series of experiments in which the mass balance of CDD/CDF was estimated within the entire combustor, beginning with the waste and ending with the stack, discount the first theory of dioxin formation (i.e., that dioxin in the feed accounts for all emissions of dioxin from the stack to the air). Moreover, it is expected that the conditions of thermal stress imposed by typical incineration and other combustion sources would destroy and reduce the CDDs and CDFs present as contaminants in the waste to levels that are 0.0001 to 10 percent of the initial concentration, depending on the performance of the combustion source and the level of combustion efficiency. Stehl et al. (1973) demonstrated that the moderate temperature of 800°C enhances the decomposition of CDDs at a rate of about 99.95 percent, but that lower temperatures result in a higher survival rate. Theoretical modeling has shown that unimolecular destruction of CDDs/CDFs at 99.99 percent can occur at the following temperatures and retention times within the combustion zone: 977°C with a retention time of 1 second; 1000°C at a retention time of 1/2 second; 1227°C at a retention time of 4 milliseconds; and 1727°C at a retention time of 5 microseconds (Schaub and Tseng, 1983). Thus, CDDs and CDFs would have to be in parts per million concentration in the feed to the combustor to be found in the part per billion or part per trillion levels in the stack gas emission (Shaub and Tseng, 1983). However, it cannot be ruled out is that CDDs/CDFs in the waste or fuel may contribute (up to some percentage) to the overall concentration leaving the stack.

3.5.2. Formation of CDDs/CDFs from Precursor Compounds

The second theory states that the production of CDDs and CDFs is a direct result of in-situ thermal degradation of precursor compounds during or after combustion of organic materials. Present theory is mostly derived from laboratory experiments involving the heating of suspect precursors in quartz ampules under starved-air conditions, and in experiments investigating the role that combustion fly ash has in promoting the formation of CDD/CDFs from precursor compounds.

Liberti and Brocco (1982) postulated that the general reaction that may be taking place in a typical combustion process is a thermolytic synthesis and interaction between two families of precursors indicated by A and B. Precursors A are aromatic compounds

having a definite phenolic structure (e.g., phenol and polychlorinated phenols), and precursors B are chemical species that can act as a chlorine donor (e.g., PVC and HCl). Esposito et al. (1980) offered a chemical basis for defining a dioxin precursor:

1. The compound is comprised of an ortho-substituted (positions 1 and 2 on the compound) benzene ring in which one of the substituents is an oxygen atom directly attached to the ring, and

2. It then must be possible for the two substituents on the benzene ring to react with each other to form a new and independent compound under the influences of heat and pressure (i.e., dioxin).

Dickson and Karasek (1987) further refined this definition to be consistent with the formation kinetics thought to occur within combustion processes. In their definition, the term "precursor" refers specifically to chlorinated aromatic compounds that are either already present on the surface of combustion fly ash, or are present in the gas phase prior to entering a critical region outside the combustion zone where the gases have cooled and where heterogeneous catalyzed reactions take place that form CDDs/CDFs. Chlorophenols and chlorobenzenes were identified as ideal precursor compounds in these reaction pathways.

Controlled laboratory combustion experiments involving the thermal degradation of aromatic compounds, either singly or in mixtures, have provided useful data in identifying ideal precursor compounds. For example, Jansson and coworkers (1977) generated CDDs through the pyrolysis of wood chips treated with tri-, tetra-, and penta-chlorophenol in a bench-scale furnace operated at 500-600°C. Stehl and Lamparski (1977) combusted grass and paper treated with the herbicide 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) in a bench-scale furnace at 600-800°C and generated ppm_v levels of TCDD. Ahling and Lindskog (1982) have reported on the formation of CDDs during the combustion of tri- and tetrachlorophenol formulations at temperatures of 500-600°C. Decreases in oxygen during combustion generally increased the yield, and the addition of copper salts to the tetrachlorophenol formulation significantly enhanced the yield of CDDs. Combustion of pentachlorophenol resulted in low yields of CDDs except when burned with an insufficient

supply of oxygen. In that case, the investigators noted the formation of tetra- through octa-chlorinated congeners. Buser (1979) generated CDDs/CDFs on the order of 0.001-0.08 percent (by weight) by heating tri-, tetra-, and pentachlorobenzenes at 620°C in quartz ampules in the presence of oxygen. It was noted that chlorophenols were formed as combustion by-products, and Buser (1979) speculated that these were acting as reaction intermediates in the formation of CDDs/CDFs.

Recently it has been demonstrated that CDDs and CDFs are formed from aromatic precursor compounds adsorbed onto the reactive surface of fly ash (particulate matter) entrained in the combustion plasma. Moreover, formation occurs outside and downstream of the combustion zone of a furnace to a combustion source in regions where the temperature of the combustion offgases has cooled to between 200 and 400°C (Vogg et al., 1987; Bruce et al., 1991; Cleverly et al., 1991; Gullet et al., 1990a; Commoner et al., 1987; Dickson and Karasek, 1987; Dickson et al., 1992). Vogg and coworkers (1987) have shown that inorganic chloride ions, such as copper chloride, present in the combustion gas may act as a catalyst to promote surface reactions on particulate matter to convert aromatic precursor compounds to chlorinated dioxins and dibenzofurans. After carefully extracting organics from MSWI fly ash, Vogg et al. (1987) added a known concentration of isotopically labeled CDDs/CDFs to the matrix. The MSWI fly ash was then heated in a laboratory furnace at varying temperatures for 2 hours. The treated fly ash was exposed to increasing temperatures in 50°C increments in a temperature range of 200 to 400°C. Table 3-21 summarizes these data.

Because the relative concentration of CDDs/CDFs increased while exposed to varying temperature, Vogg, et al. (1987, 1992) concluded that formation of CDDs and CDFs from precursor compounds on the surface of fly ash transpires during MSW incineration within a specific range of temperature, 250 to 450°C. Within this range, the concentration of CDDs/CDFs increases to some maxima, and outside this range the concentration diminishes. Vogg et al. (1987) proposed an oxidation reaction pathway giving rise to the formation of CDDs and CDFs in the post-furnace regions of the incinerator in the following order: (1) hydrogen chloride gas (HCl) is thermolytically derived as a product of the combustion of heterogeneous fuels containing abundant chlorinated

Table 3-21. Concentration of CDDs/CDFs on Municipal Incinerator Fly Ash at Varying Temperatures.

Congener	CDD/CDF Concentration on Fly Ash (ng/g)				
	Temperature (°C)				
	200°	250°	300°	350°	400°
CDD					
Tetra	15	26	188	220	50
Penta	40	110	517	590	135
Hexa	65	217	1029	550	110
Hepta	100	208	1103	430	60
Octa	90	147	483	200	15
CDF					
Tetra	122	560	1379	1185	530
Penta	129	367	1256	1010	687
Hexa	61	236	944	680	260
Hepta	48	195	689	428	112
Octa	12	74	171	72	12

Source: Adapted from Vogg et al. (1987).

organic chemicals and chlorides; (2) oxidation of HCl, with copper chloride ($CuCl_2$) as a catalyst, yields free gaseous chlorine; (3) phenolic compounds (present from combustion of lignin in the waste or other sources) entrained in the combustion plasma are substituted on the ring structure by contact with the free chlorine; and (4) the chlorinated precursor to dioxin (e.g., chlorophenol) is further oxidized (with copper chloride as a catalyst) to yield CDDs and CDFs and chlorine.

Gullett and coworkers (1990a; 1990b; 1991a; 1991b; 1992) have studied the formation mechanisms through extensive combustion research at EPA, and have verified the observations of Vogg et al. (1987). It was proven that CDDs and CDFs could be ultimately produced from low temperature reactions (i.e., 350°C) between Cl_2 and a phenolic precursor combining to form a chlorinated precursor, followed by oxidation of the chlorinated precursors (catalyzed by a copper catalyst such as copper chloride) as in examples (1) and (2), below.

(1) The initial step in the formation of dioxin is the formation of chlorine from HCl in the presence of oxygen (the Deacon process), as follows (Vogg et al., 1987; Bruce et al., 1991):

$$2HCl + 1/2\ O_2 \xrightarrow{\Delta} H_2O + Cl_2$$

(2) Phenolic compounds adsorbed on the surface of fly ash are chlorinated to form the dioxin precursor, and the dioxin is formed as a product from the breakdown and molecular rearrangement of the precursor. The reaction is promoted by the presence of heat and copper chloride acting as a catalyst (Vogg et al., 1987; Gullett et al., 1992):

(a) $\text{phenol} + Cl_2 \longrightarrow \text{chlorophenol (dioxin precursor)}$

(b) $\text{2-chlorophenol} + 1/2\ O_2 \xrightarrow{CuCl_2} \text{dioxin} + Cl_2$

The major direct source of chlorine available for participating in the formation of CDDs/CDFs is gaseous HCl, which is initially formed as a combustion by-product from the

chlorine and chlorinated organic chemicals contained in the MSW (and other fuels) (Vogg et al., 1987; Bruce et al., 1991; Cleverly, 1984; Commoner et al., 1987). MSW contains approximately 0.45-0.90 percent (by weight) chlorine (Domalski et al., 1986). MSW incinerators are a major stationary combustion source of air emissions of HCl, which average between 400 to 600 ppm in the combustion gas (U.S. EPA, 1987). HCl is converted to chlorine vapor by the Deacon process, and the vapor phase chlorine directly chlorinates a dioxin precursor along the aromatic ring structure. Oxidation of the chlorinated precursor in the presence of an inorganic chloride metal catalyst (of which copper chloride was found to be the most active) yields CDDs and CDFs. Increasing the yield of chlorine in vapor phase from the oxidation of HCl generally causes an increase in the rate of formation of CDDs/CDFs. Formation kinetics are most favored at temperatures between 200 to 350°C. Reductions in chlorine production, either by limiting initial HCl concentration or by shortening the residence time in the Deacon process temperature window, should result in decreases in the rate and magnitude of formation of CDDs and CDFs (Bruce et al., 1991; Gullett et al., 1990b; Commoner et al., 1987). Bruce and coworkers (1991) observed a general increase in the formation of CDDs and CDFs with increases in the vapor phase concentration of chlorine. Figure 3-2 shows the apparent dependence of the extent of formation of CDDs and CDFs upon chlorine concentration in the vapor phase. Bruce et al. (1991) verified a dependence on the concentration and availability of gaseous chlorine in the thermolytic formation of CDDs/CDFs.

In the testing of a variety of industrial stationary combustion sources during the National Dioxin Study in 1987, EPA made a series of qualitative observations on the relationship between total chlorine present in the fuel/waste and the magnitude of emissions of CDDs and CDFs from the stack of the tested facilities (U.S. EPA, 1987). In general, combustion units with the highest CDD emission concentrations had greater quantities of chlorine in the fuel, and, conversely, sites with the lowest CDD emission concentrations contained only trace quantities of chlorine in the feed. The typical chlorine content of various combustion fuels has been reported by Lustenhouwer et al. (1980) as: coal: 1,300 μg/g; MSW: 2,500 μg/g; leaded gasoline: 300-1,600 μg/g; unleaded gasoline: 1-6 μg/g.

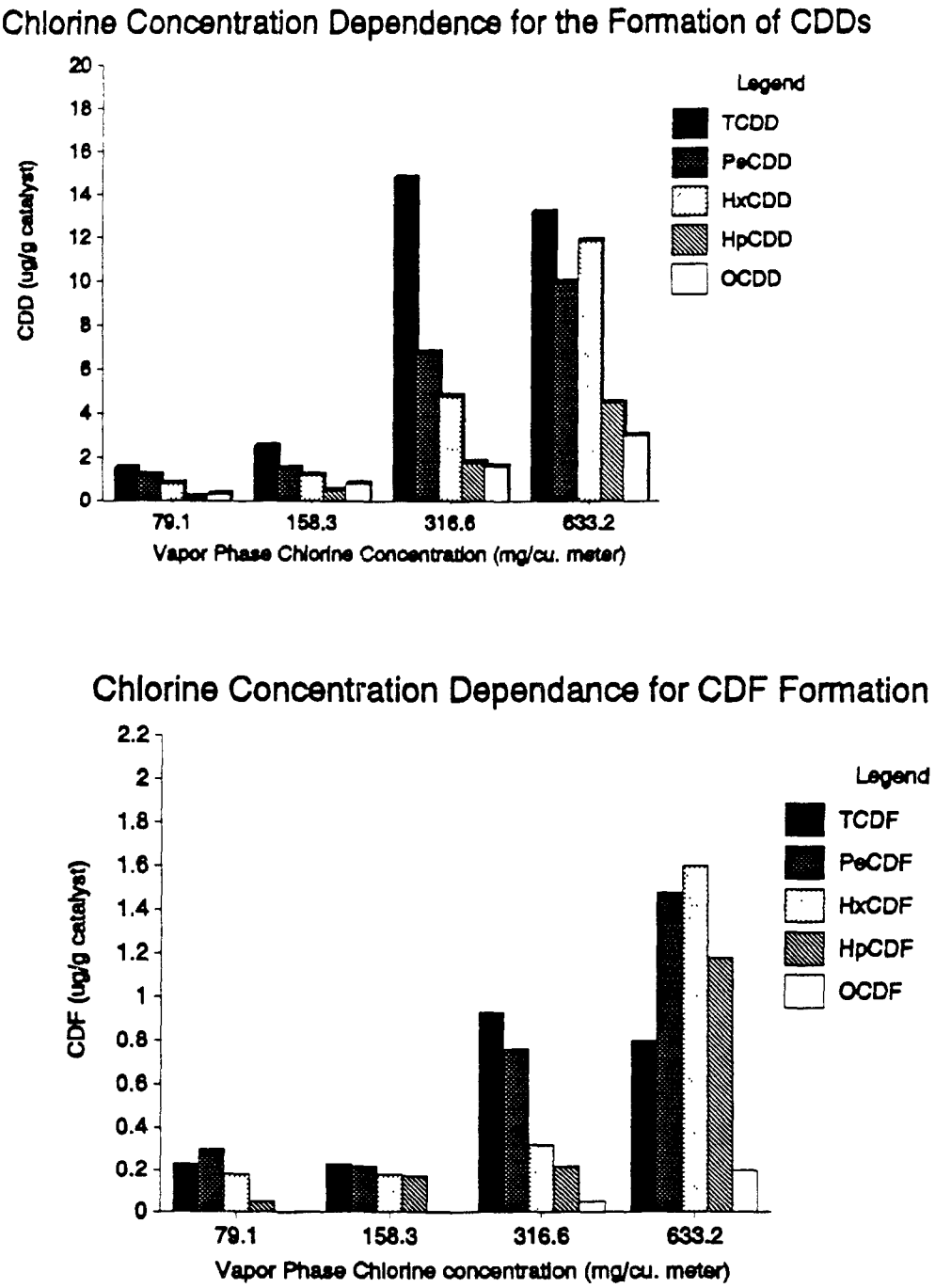

Figure 3-2. The Association Between Vapor Phase Cl_2 and the Formation of CDDs/CDFs.

The role that temperature plays in the formation kinetics has been investigated by Oberg et al. (1989) on a full-scale hazardous waste incinerator operating in Sweden. Oberg confirmed that the formation of CDDs/CDFs occurs after the furnace. Most of the formation transpired in the boiler used to extract heat for co-generation of energy. In this investigation, significant increases in total concentration of dioxin TEQ occurred between temperatures of 280-400°C, and concentrations declined at temperatures above 400°C. This is in agreement with the experimental evidence of the temperature range defined as the "window of opportunity" for catalytic formation of CDDs/CDFs on the surfaces of fly ash particles.

Dickson and Karasek (1987) have demonstrated that CDDs/CDFs can be directly formed from the thermal conversion and oxidation of chlorinated precursors, in particular chlorophenols, on the surface of MSWI fly ash while heated in a bench-scale furnace. Their experiment was designed to mimic conditions of MSW incineration; to identify the step-wise chemical reactions involved in converting a precursor compound into dioxin, and to determine if MSWI fly ash could promote these reactions. MSWI fly ash was obtained from a facility in Canada and a facility in Japan. The MSWI fly ash was extensively solvent-extracted for any organic constituents prior to initiating the experiment. Twenty grams of fly ash were introduced into a bench-scale oven (consisting of a simple flow-tube combustion apparatus) and heated at 340°C overnight to desorb any remaining organic compounds from the matrix. $^{13}C_{12}$ -labeled pentachlorophenol (PCP) and two trichlorophenol isotopes ($^{13}C_{12}$- 2,3,5-T and 3,4,5-T) were added to the surface of the clean fly ash matrix, and placed into the oven for 1 hour at 300°C. Pure inert nitrogen gas (flow rate of 10 ml/min) was passed through the flow tube to maintain constant temperatures. Tetra- through octa- CDDs were formed from the labeled pentachlorophenol experiment; over 100 μg/g of total CDDs were produced. The congener pattern was similar to the congener pattern found in MSWI emissions. The 2,4,5-T experiment primarily produced HxCDDs and very small amounts of tetra- and octa-CDD. The 3,4,5-T experiment mainly produced OCDD and 1,2,3,4,6,7,8-HpCDD. Dickson and Karasek (1987) proposed that the chlorinated phenol may undergo molecular rearrangement or isomerization as a result of dechlorination, dehydrogenation, and trans-chlorination before

condensation occurs to ultimately form CDDs on the fly ash surface. These reactions ultimately dictate the types and amounts of CDDs that are formed.

Nestrick and coworkers (1987) reported on the thermolytic reaction between benzene (an unsubstituted precursor) and iron (III) chloride on a silicate surface to yield CDDs/CDFs at temperatures ≥ 150°C. The experimental protocol was to introduce 100 - 700 mg of native and $^{13}C_6$-benzene into a macro-reactor system consisting of a benzene volatilization chamber connected to a glass tube furnace. The investigators noted the relevance of this experiment to generalizations about combustion processes because benzene is the usual combustion by-product of organic fuels. Inert nitrogen gas was used to carry the benzene vapor to the furnace area. The exit to the glass tubing to the furnace was plugged with glass wool, and silica gel was introduced from the entrance end to give a bed depth of 7 cm to which the $FeCl_3$ was added to form a $FeCl_3$/silica reagent. The thermolytic reaction took place in a temperature range of 150-400°C at a residence time of 20 minutes. Although di- through octa-CDD/CDF were formed by this reaction at all the temperatures studied, the percent yields were extremely small. Table 3-22 summarizes these data.

3.5.3. The *de novo* Synthesis of CDDs/CDFs During Combustion of Organic Materials

The third and last theory states that CDDs/CDFs are formed in combustion processes from materials and/or compounds that are not structurally related to CDDs/CDFs on a molecular level. As in Theory 2, synthesis is believed to occur in regions outside of the furnace zone of the combustion process where the combustion plasma has cooled to a range of temperatures considered favorable to formation kinetics. A key component to *de novo* synthesis is the production of intermediate compounds (either halogenated or non-halogenated) that are precursors to dioxin formation. However, research in this area has produced CDDs/CDFs directly from the heating of carbonaceous fly ash in the presence of an inorganic ion without the apparent generation of reactive intermediates. Thus, the specific steps involved in the *de novo* process have not been fully and succinctly delineated. Laboratory experimentation has proven that MSWI fly ash, itself, is not an inert substrate, and the matrix can actually participate in the formation kinetics. Typically

Table 3-22. CDDs/CDFs Formed From the Thermolytic Reaction of 690 mg Benzene + $FeCl_3$Silica Complex.

Congener	Mass Produced (ng)	Number of Moles Produced	Percent Yield[a]
DiCDD	4.9	0.019	4.3 E-7
TriCDD	54	0.019	4.3 E-6
TCDD	130	0.400	9.0 E-6
PeCDD	220	0.620	1.4 E-5
HxCDD	170	0.440	9.9 E-6
HpCDD	98	0.230	5.2 E-6
OCDD	20	0.040	9.0 E-7
Total CDDs	696.9	1.940	4.4 E-5
DiCDF	990	4.200	9.5 E-5
TriCDF	7,800	29.00	6.6 E-4
TCDF	12,000	39.00	8.8 E-4
PeCDF	20,000	59.00	1.3 E-3
HxCDF	33,000	88.00	2.0 E-3
HpCDF	40,000	98.00	1.1 E-3
OCDF	74,000	167	3.8 E-3
Total CDFs	187,790	484.2	1.1 E-2

[a] Percent yield = (number moles CDD/moles benzene) x 100.

Source: Nestrick et al. (1987)

the fly ash is composed of an alumina-silicate construct with 5-10 percent concentrations of silicon, chlorine (as inorganic chlorides), sulfur, and potassium (NATO, 1988). Twenty percent of the weight of fly ash particles are carbon, and the particles have specific surface areas in the range of 2-4 m^2 (NATO, 1988). The distinguishing feature of the *de novo* synthesis over the precursor synthesis is the thermolytic breakdown and molecular rearrangement of chemical species unrelated to CDDs/CDFs at the start of the process to yield precursor compounds. Theory 2 starts with the precursor compounds already adsorbed onto the surface of fly ash or present in the gas phase (Dickson et al., 1992). By this distinction, however, one could argue that Theory 3 is really an augmentation to Theory 2 because the generation of CDDs/CDFs may still require the formation of a dioxin precursor. Nevertheless, a distinction is presented here for purposes of describing additional pathways that have been suggested for the thermal formation of these compounds.

To delineate the *de novo* synthesis of CDDs/CDFs from unrelated matter, Stieglitz and coworkers (1989a) have conducted experiments involving the heating of particulate carbon containing adsorbed mixtures of Mg and Al-silicate in the presence of copper chloride as a catalyst to the reaction. The authors described annealing mixtures of Mg-Al silicate with activated charcoal (4 percent by weight), chloride as potassium chloride (7 percent by weight), and 1 percent copper chloride ($CuCl_2$) (in water) in a glass tube at 300°C. The retention time was varied at 15 minutes, 30 minutes, and 1, 2, and 4 hours to obtain differences in the amounts of CDDs/CDFs that could be formed. The results are summarized in Table 3-23.

In addition to the CDDs/CDFs formed as primary products of the *de novo* synthesis, the investigators observed the formation of precursors at the varying retention times of the experiment. In particular, similar yields of tri- though hexa-chlorobenzenes, tri- through hepta-chloronaphthalenes, and tetra- through hepta-chlorobiphenyls, were quantified which were seen as highly suggestive of the role these compounds may play as intermediates in the continued formation of CDDs/CDFs. Table 3-24 summarizes the experimental yields of chlorinated benzenes as a function of the annealing time at 300°C. Stieglitz et al. (1989a) made the following observations:

Table 3-23. *De Novo* Formation of CDDs/CDFs After Annealing Mg-Al Silicate, 4% Charcoal, 7% Cl, 1% $CuCl_2.2H_2O$ at 300°C.

Congener	Concentrations of CDD/CDF (ng/g)				
	Reaction Time (hrs)				
	0.25	0.5	1	2	4
TCDD	2	4	14	30	100
PeCDD	110	120	250	490	820
HxCDD	730	780	1600	2200	3800
HpCDD	1700	1840	3500	4100	6300
OCDD	800	1000	2000	2250	6000
Total CDD	3342	3744	7364	9070	17020
TCDF	240	280	670	1170	1960
PeCDF	1360	1670	3720	5550	8300
HxCDF	2500	3350	6240	8900	14000
HpCDF	3000	3600	5500	6700	9800
OCDF	1260	1450	1840	1840	4330
Total CDF	8360	10350	17970	24160	38390

Source: Stieglitz et al. (1989a).

Table 3-24. *De Novo* Formation of Chlorinated Benzenes (CBzs), Polychlorinated Naphthalenes (PCNs), and Polychlorinated Biphenyls (PCBs) after Annealing Mg-Al Silicate, 4% Charcoal, 7% Cl, 1% $CuCl_2.2H_2O$

	Concentrations (ng/g)				
	Reaction Time (hrs)				
	0.25	0.5	1	2	4
CBzs					
1,2,5-T3CBz	80	90	220	290	520
1,2,4-T3CBz	330	1080	1620	3470	4500
1,2,3-T3CBz	660	2580	2890	5700	6300
1,2,4,5-T4CBz	440	1700	2380	5150	6000
1,2,3,5-T4CBz	1080	4200	6300	9400	11300
1,2,3,4-T4CBz	2280	9700	11250	19100	20500
P5CBz	4240	---	21000	37000	40300
H6CBz	2640	11500	10700	18300	2138
PCNs					
T4CN	60	80	130	220	360
P5CN	75	125	220	360	440
H6CN	125	190	270	425	760
PCBs					
T4CB	5	10	45	40	35
P5CB	70	75	160	260	375
H6CB	60	70	120	170	210
H7CB	40	60	90	130	160

Source: Stieglitz et al. (1989a).

1. The *de novo* synthesis of CDDs/CDFs via the reaction of carbonaceous particulate matter exposed to a temperature of 300°C was clearly demonstrated. Additionally, the experiment yielded ppb-ppm concentrations of chlorinated benzenes, chlorinated biphenyls, and chlorinated napthalenes through a similar mechanism. When potassium bromide was substituted for potassium chloride as a source of halogen for the organic compounds in the reaction, polybrominated dibenzo-p-dioxins and dibenzofurans were formed as reaction products.

2. Copper chloride catalyzed the *de novo* synthesis of CDDs/CDFs on the surface of particulate carbon in the presence of oxygen to yield carbon dioxide and chlorinated/brominated aromatic compounds.

3. Particulate carbon, which is characteristic of combustion processes, may act as the source for the direct formation of CDDs/CDFs as well as other chlorinated organics.

More recently, Stieglitz and coworkers (1991) investigated the role that particulate carbon plays in the *de novo* formation of CDDs/CDFs from fly ash containing appreciable quantities of organic chlorine. Stieglitz et al. (1991) found that the fly ash contained 900 μg/g of bound organic chlorine. Only 1 percent of the organic chlorine was extractable. Annealing the fly ash at 300-400°C for several hours caused the carbon to oxidize leading to a reduction in the total organic chlorine in the matrix, and a corresponding increase in the total extractable organic chlorine (TOX) (e.g., 5 percent extractable TOX at 300°C and 25-30 percent extractable total organic chlorine at 400°C). From this, Stieglitz et al. (1991) concluded that the oxidation and degradation of carbon in the fly ash are the source for the formation of CDDs/CDFs, and, therefore, are essential in the *de novo* synthesis of these compounds.

Addink et al. (1991) conducted a series of experiments to observe the *de novo* synthesis of CDDs/CDFs in a carbon-fly ash system. In this experiment, 4 grams of carbon-free MSWI fly ash were combined with 0.1 gram of activated carbon and placed into a glass tube between two glass wool plugs. The glass tube was then placed into a furnace at a specific temperature in the range 200 to 400°C. This was repeated for a series of retention times and temperatures. The investigators observed that the formation

of CDDs/CDFs was optimized at the temperature of 300°C and at the furnace retention times of 4-6 hours. Figure 3-3 displays the relationship between retention time, temperature and the production of CDDs/CDFs from the heating of carbon particulate. Addink et al. (1991) also investigated the relationship between temperature of the furnace

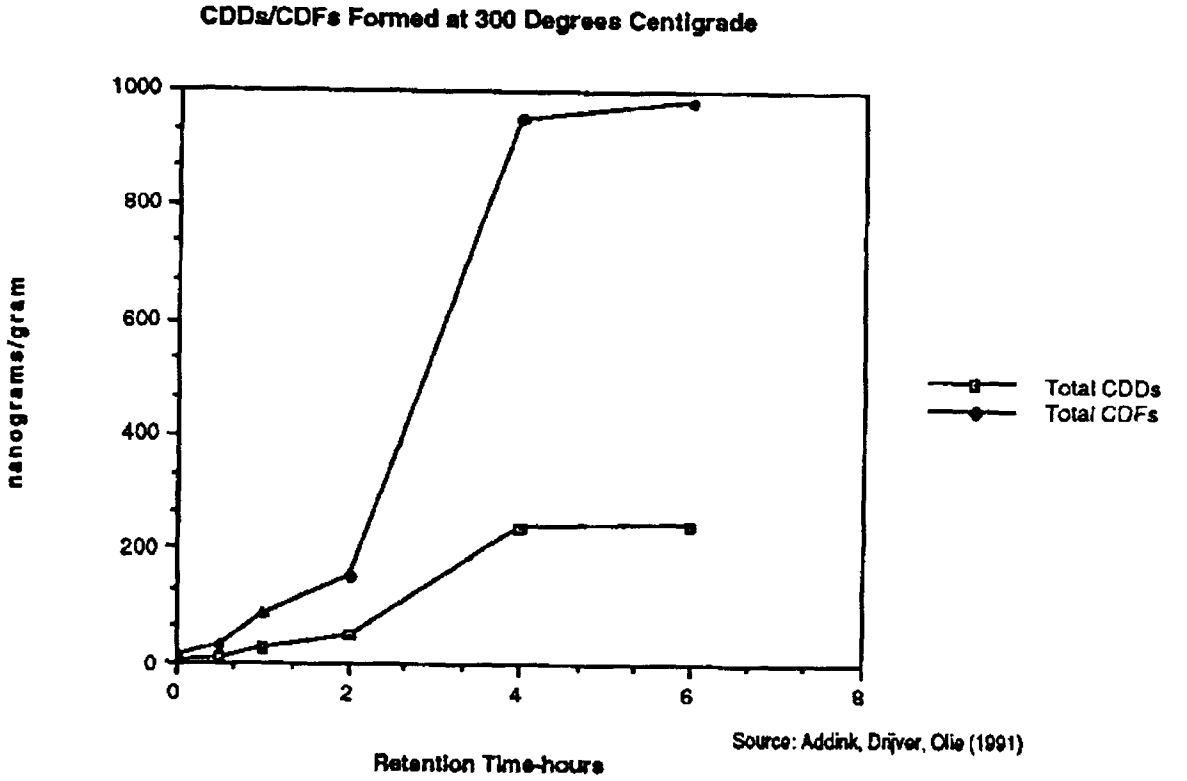

Figure 3-3. The *de novo* Synthesis of CDD/CDFs from Heating Carbon Particulate at 300°C at Varying Retention Times.

and the production of CDDs/CDFs from the annealing of carbonaceous fly ash. Figure 3-4 displays this relationship. In general, the concentration began to increase at 250°C and crested at 350°C, with a sharp decrease in concentration above 350°C. The authors also noted a relationship between temperature and the CDD/CDF congener profile; at 300°C to 350°C, the lower chlorinated tetra- and penta-CDD/CDF congeners increased in concentration, while hexa-, hepta-, and octa-CDD/CDF congeners either remained the same or decreased in concentration. The congener profile of the original MSWI fly ash (not subject to *de novo* experimentation) was investigated with respect to changes caused

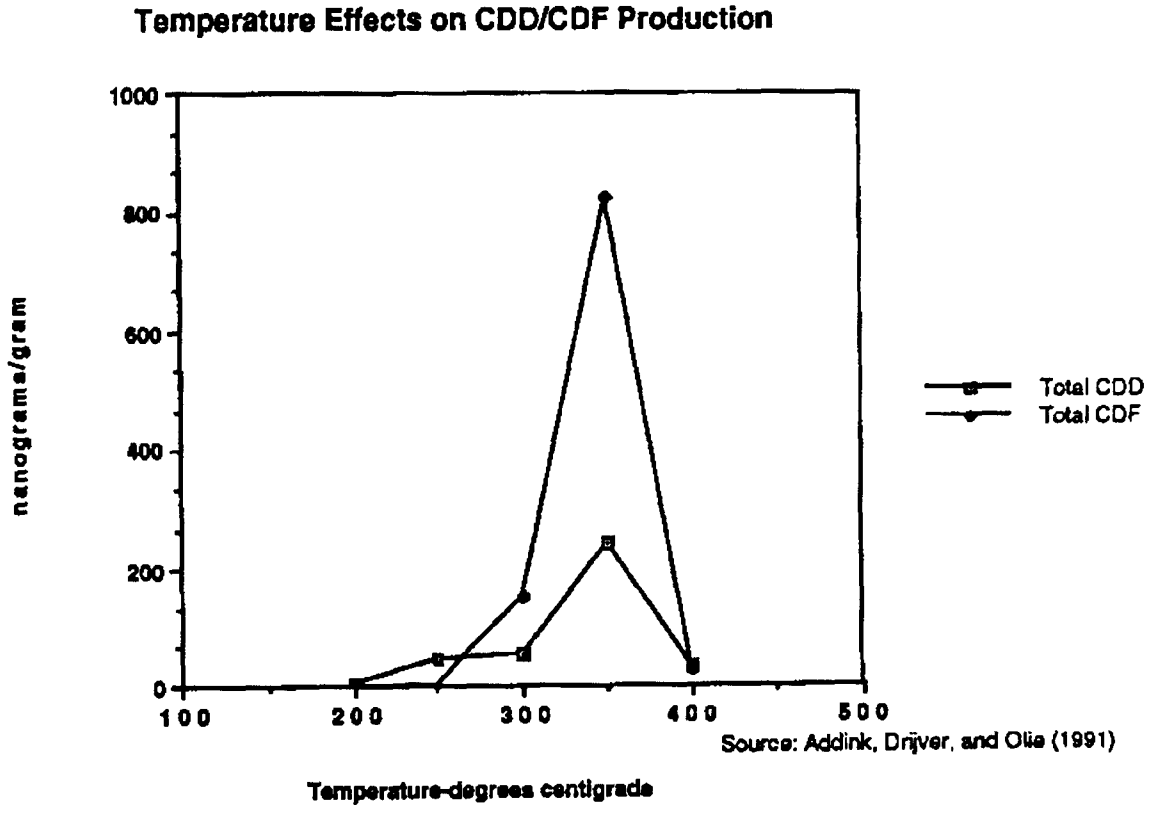

Figure 3-4. Relationship Between Temperature and the *de novo* Formation of CDDs/CDFs.

by either temperature or residence time in the furnace. No significant changes occurred, leading the authors to propose an interesting hypothesis for further testing: after formation of CDDs/CDFs occurs on the surface of fly ash, the congener profile remains fixed and insensitive to changes in temperature or residence time indicating some form of equilibrium is reached in the formation kinetics.

Gullett et al. (1994) developed a pilot-scale combustor to study the effect on CDD/CDF formation of varying the combustion-gas composition, temperature, residence time, quench rate, and sorbent ($Ca[OH]_2$) injection. The fly ash loading was simulated by the injection on fly ash collected from a full-scale MSWI. Sampling and analysis indicated CDD/CDF formation or the injected fly ash at levels representative of those observed at full-scale MSWIs. A statistical analysis of the results showed that, although the effect of

combustor operating parameters of CDD/CDF formation is interactive and very complicated, substantial reduction in CDD/CDF formation can be realized with high temperature sorbent injection to reduce HCl or Cl_2 concentrations, control of excess air (also affects ratio of CDDs to CDFs formed), and increased quench rate.

The *de novo* theory also considers the generation of CDDs/CDFs from the combustion of PVC resin. Key to the *de novo* synthesis of CDDs/CDFs is the initial formation of HCl from combustion. Paciorek and coworkers (1974) thermally degraded pure PVC resin at 400°C and produced 550 mg/g HCl vapor as a primary thermolysis product, which was observed as being 94 percent of the theoretical amount based on the percent weight chlorine on the molecule. Ahling et. al. (1978) have concluded that HCl can act as a chlorine donor to ultimately yield chlorinated aromatic hydrocarbons from the thermolytic degradation of pure PVC, and that these yields are a function of transit time, percent oxygen, and temperature. The data they observed from 11 separate experiments conducted with a range of temperatures from 570-1130°C indicated that significant quantities of various isomers of dichloro-, trichloro-, tetrachloro-, and hexachlorobenzenes could be produced. Choudhry and Hutzinger (1983) proposed that the radical species Cl· and H· generated in the incineration process may attack the chlorinated benzenes thus formed, and abstract hydrogen atoms to produce ortho-chlorine substituted chlorophenol radicals. These intermediate radical species then react with molecular oxygen to yield ortho-substituted chlorophenols. As a final step, the ortho-substituted chlorophenols act as ideal precursors to yield CDDs/CDFs with heat and oxygen.

Although most of the aforementioned experiments have involved the pyrolysis of anthropogenic substances, the *de novo* formation of CDDs/CDFs is theoretically proposed to include the combustion of autochthonous (naturally occurring) organic substances (Choudhry and Hutzinger,1983) in the presence of a chlorine donor. This possibility was first advanced by scientists at Dow Chemical Co. in 1978 in a proposed working hypothesis known as "the trace chemistries of fire" (Crummett, 1982). This proposed working hypothesis was based on the following observations:

1. Combustion processes are seldom more than 99.9 percent efficient in converting carbonaceous fuel into carbon dioxide.

2. The remaining 0.1 percent of the fuel is converted into traces of organic species including complex halogenated aromatic hydrocarbons. Most of these compounds have not been identified in combustion emissions.

3. Municipal solid waste and fossil fuels contain complex mixtures of diverse chemical species at variable concentrations.

4. Combustion fuels contain chlorine in a range of 1-5000 parts per million.

5. Particulate matter that is emitted from oil-fired heating and power plants contain vanadium and nickel. Particulates emitted from coal-fired power plants contain vanadium, nickel, iron, and manganese. In combination with silicon and unburned carbon, these species can act as catalysts in the combustion process to form halogenated aromatic hydrocarbons.

6. Chemical reactions that occur in flames include pyrolysis, oxidation, and reduction. Ions, electrons, free radicals, and free atoms interact in a continuously changing environment.

7. Dow scientists found traces of CDDs/CDFs in all particulate matter samples taken from areas that were in close proximity to combustion sources.

8. Precursors for the formation of CDDs have been experimentally proven, and have been identified to be primarily chlorinated phenols and chlorinated benzenes. Because the pyrolysis of polyvinyl chloride (PVC) produces chlorobenzenes, the combustion of PVC may cause the formation of CDDs/CDFs.

Dow Chemical Co. invited the scientific community at large to give advice on ways in which the trace chemistries of fire hypothesis could be tested. The following studies were proposed as a means of testing the hypothesis (Crummett, 1982):

1. Determine if CDDs/CDFs are present in soils (having a relatively high carbon content) taken from drill cores beneath ancient lake beds at depths corresponding to 5, 12, and 35,000 years of sedimentation and deposition.

2. Determine if CDDs/CDFs are present in ice core samples taken from the center of an ancient glacier.

3. Determine if CDDs/CDFs are present in volcanic ash.

4. Determine if CDDs/CDFs are present in sea breezes from remote islands in the South Pacific.

5. Determine if CDDs/CDFs can be formed by the combustion of fossil fuels in the presence of chlorine or inorganic chloride.

6. Determine if CDDs/CDFs can be detected in fish species taken from rivers remote from chemical manufacturing but close to incinerators and fossil-fueled power plants.

Although these studies were proposed in 1978, only items (3), (5) and (6) have even been partially addressed. Thus the "trace chemistries of fire" remains largely a working hypothesis that is in need of further testing and proving through well designed and conducted field sampling and laboratory research programs. Nevertheless, there exists some empirical evidence in this area.

Liberti et al. (1983) showed that CDDs/CDFs could be produced from the combustion of pure vegetable extracts in the presence of chlorine gas and oxygen. Pyrolytic degradation of extracts of chestnut, mimosa, and tannic acid was accomplished in a bench-scale thermal reactor. When combustion proceeded without chlorine gas, phenolic compounds and cresol were formed as primary thermolysis products. When the vegetable extracts were burned in association with chlorine gas or PVC plastic, chlorophenols and CDDs/CDFs were formed. Liberti et al. (1983) postulated that the PVC was acting as a chlorine donor in the formation of CDDs/CDFs from phenolic compounds, and that the chlorine gas directly formed the chlorinated precursor from a phenolic (pre-dioxin) ring structure. Table 3-25 summarizes these experiments.

There is some empirical evidence that the burning of wood, in the presence of chlorine or inorganic chlorides, may form CDDs/CDFs, although the evidence is not conclusive. Few of these experiments had ruled out contamination of the wood fiber by known chlorinated precursors through extraction and chemical analysis. None of the cited

Table 3-25. CDDs/CDFs Formed from the Combustion of Vegetable Extracts in the Presence of Chlorine Gas.

Congener	CDF (μg/g)			CDD (μg/g)		
	Chestnut	Mimosa	Fruit	Chestnut	Mimosa	Fruit
Tri	trace	trace	21	trace	trace	35
Tetra	trace	trace	47	trace	trace	74
Penta	101	62	40	trace	trace	62
Hexa	90	2	44	trace	trace	16
Hepta	28	6	15	28	10	15
Octa	80	25	ND	38	6	ND

Source: Adapted from Liberti et al. (1983).

experiments attempted to determine if the wood fiber was contaminated by CDDs/CDFs prior to the conduct of the experiment. If the atmosphere serves to widely distribute CDDs/CDFs, and if CDDs/CDFs can exist in the vapor and particle phases in the ambient air, then trees and other biomass can become reservoirs of CDD/CDF contamination by means of particle deposition onto and vapor diffusion into the biomass. Until these possibilities have been addressed and their impacts, if any, are quantified, experiments in which CDDs/CDFs are generated from the combustion of wood must be interpreted with a certain degree of caution, especially with regard to proving that CDDs/CDFs can be formed in nature without human intervention.

Ahling and Lindskog (1982) demonstrated that the combustion of untreated wood in an open fire can generate relatively high concentrations of chlorinated aromatic hydrocarbons in the emissions. These compounds include established dioxin precursors such as di- through hexa-chlorobenzene and tetra- and penta- chlorinated phenols in ppb_v-ppm_v concentrations. In addition, ppm_v levels of benzene were produced. The presence of chlorinated precursors indicates that inorganic chlorides in the plant may be capable of chlorinating unsubstituted aromatic structures. Reaction kinetic experiments involving the formation of HCl vapor (Olie et al., 1983; Choudhry and Hutzinger, 1983) have shown that

HCl can be formed from inorganic chlorides as a result of a reaction between sulfur dioxide and sodium chloride during combustion, as follows:

$$2\ NaCl + SO_2 + 1/2\ O_2 + H_2O \xrightarrow{\Delta} Na_2SO_4 + HCl$$

or: HCl can be liberated by the catalytic reaction of NaCl and a metal oxide. The general reaction is:

$$NaCl + H_2O + (A) \xrightarrow{\Delta} (B) + HCl$$

where: (A) is a metal oxide, i.e.: Al_2O_3, Fe_2O_3.

Olie et al. (1983) conducted wood burning experiments in a bench-scale combustion unit. Wood treated with pentachlorophenol was incinerated to generate CDDs/CDFs in one experiment, and 60-year-old wood from the demolition of a residence

was burned in a separate experiment. The authors alleged that the 60-year-old wood predated the manufacture and use of phenoxy wood preservatives and, therefore, probably was absent any dioxin precursors; however, this was not analytically confirmed. They did not directly monitor the smoke emissions for the presence of CDDs/CDFs, only the collected fly ash. CDDs/CDFs were detected in the fly ash in ppb_w concentrations. However, the authors noted that the quantified CDDs/CDFs could have occurred as a consequence of the previous tests of burning wood treated with pentachlorophenol.

Nestrick and Lamparski (1983) conducted studies on residential wood combustion to evaluate the possibility that CDDs may form. This was accomplished through the evaluation of soot scrapings from the chimneys of wood burning stoves. Samples were taken at random from the eastern, central, and western regions of the United States. Average total CDD levels in the chimney flue scrappings were: 8.3 ppb in the eastern region, 42.5 ppb in the central region, and 9.9 ppb in the west.

EPA tested a freestanding noncatalytic residential wood stove for chimney flue gas emissions of CDDs/CDFs during the combustion of pine and oak (U.S. EPA, 1987d). Through a series of tests, it was determined that the wood fiber was free of known chlorinated precursors (e.g., PCBs, chlorinated benzenes, and chlorinated phenols). The total chloride concentration was found to be 125 ppm for the oak and 49 ppm for the pine wood prior to burning in the wood stove. The combustion of the wood generated ppm levels of aromatic hydrocarbon compounds. This relatively high loading of emissions on the sampling device interfered with any speciation of CDD/CDF compounds in the emissions. However, combustion ash samples provided an alternative matrix for evaluation. The analysis of ash samples from the unit showed that only OCDD was present as a dioxin contaminant at a maximum concentration of 0.09 ppb (by weight). Wipe samples were also taken from inside the chimney flue. OCDD and hepta-CDD were detected in the chimney soot at a maximum concentration of 0.6 ppb and 0.04 ppb, respectively. No lower chlorinated CDDs nor any CDFs were found in the ash or soot wipes.

Choudhry and Hutzinger (1983) have postulated that the complex structure of lignin in wood fiber can pyrolyze to generate CDDs/CDFs if a chlorine donor is present. This

theory is based on the experiments of Kirsbaum et al. (1972) in which two lignin preparations (spruce and asp) were thermally degraded in glass tubes at 475°C to yield an array of hydrocarbons, including phenol. If phenol could be formed, and if gaseous forms of inorganic or organic chlorine are available, then the phenol could be chlorinated to form a chlorophenol compound. The latter is then a precursor to the ultimate formation of CDDs/CDFs. In addition, Choudhry and Hutzinger (1983) indicated that continued pyrolysis of other hydrocarbons identified as thermolysis products in the combustion of lignin could ultimately yield benzene. Nestrick et al. (1987) demonstrated that benzene can react with an inorganic chloride in the presence of heat to produce a variety of chlorinated aromatic compounds including CDDs/CDFs. If these thermolytic pathways are operational in lignin pyrolysis, then, in theory, it is possible that forest fires can generate CDDs/CDFs in the smoke, which has been proposed by Clement and Tashiro (1991). Because of the potential importance of lignin pyrolysis as a potential, yet unverified, combustion source of CDDs/CDFs in the environment, additional research should be directed in this area. In the conduct of combustion experiments involving the pyrolysis of lignin, attention should be given to the identification of any CDDs/CDFs or precursor compounds that may exist as contaminants. Only after sample contamination has been completely ruled out can the researcher draw convincing conclusions from the experiment.

Coal is a naturally occurring substance having the potential to form CDDs when combusted. Mahle and Whiting (1980) first reported on the results of high temperature combustion of bituminous coal in a bench scale furnace with the addition of HCl, NaCl, or Cl_2↑ and air to yield CDDs. Table 3-26 summarizes these experiments. In experiment III, tetra through octa-CDDs were formed from the oxidation of coal by air which had been bubbled through a solution of hydrochloric acid. In a review of this experiment, Choudhry and Hutzinger (1983) postulated that the hydrochloric acid aided in the chlorination of aromatic hydrocarbons produced as combustion byproducts. This was also the case in experiment IV in which chlorine gas was introduced into the oxidation of coal. Experiment IV produced the highest yield of tetra- through octa-CDDs. When coal was combusted only with air, the exothermic reaction did not generate detectable quantities of tetra- or

Table 3-26. CDDs/CDFs Formed from the Combustion of Coal in the Presence of NaCl, Cl_2, or Hydrochloric Acid.

Experiment No.	Condition	Quantity Formed (ng/g of coal)			
		TCDDs	HxCDDs	HpCDDs	OCDD
I	coal + air	ND(.08)	ND(.1)	0.57(.3)	1.3(.7)
II	coal + air + NaCL	ND(.07)	ND(.2)	0.40(.24)	2.7(.5)
III	coal + air + HCl	1.4(.06)	8.4(.1)	25.0(.3)	64(.6)
IV	coal + air + Cl_2	1.2(.3)	29 (.4)	91.0(2)	290(.3)

ND = Not detected; detection limit in parentheses ( ).

Source: Mahle and Whiting (1980).

hexa- CDDs. Experiment I yielded only hepta- and octa-CDD in quantities close to the detection limit.

3.5.4 Theory on the Emission of Polychlorinated Biphenyls

The air emission of polychlorinated biphenyls (PCBs) from MSW incinerators is less understood. There are virtually no theories explaining the detection of these compounds in incinerator emissions nor other combustion sources, the exception being the intentional destruction of PCBs in hazardous waste incinerators in which case 99.9999 percent destruction rated efficiency (DRE) must be achieved. When this occurs, 0.0001 percent of the initial amount of PCBs fed into the hazardous waste incinerator may be emitted out the stack. This may indicate that some small fraction of the PCBs present in the fuel fed into an incineration process may result in emissions of PCBs from the stack of the process.

PCBs have been measured as contaminants in the raw refuse prior to incineration in an MSWI (Choudhry and Hutzinger, 1983; Federal Register, 1991). It is possible to use this information to test Theory 1 involved in CDD/CDF emissions: that the PCB contamination present in the fuel is responsible for emissions from the stack. The mass balance of total PCB beginning with measurement in the raw refuse and ending with measurement at the stack to an RDF MSW incinerator (Federal Register, 1991) can be used to calculate the destruction rated efficiency (DRE) of incineration of the PCB contaminated MSW. Using results from test number 11 at the RDF facility (Federal Register, 1991), a computation of DRE can be made with the following equation (Brunner, 1984):

$$DRE = \left(\frac{W_i - W_o}{W_i}\right) 100\% \qquad (3\text{-}1)$$

where:

W_i = mass rate of contaminant fed into the incinerator system

W_o = mass rate of contaminant exiting the incinerator system

In test 11, 811 nanograms of total PCBs/gram of refuse (ng/g) were measured in the MSW fed into the incineration system, and 9.52 ng/g of total PCB were measured at the inlet to the pollution control device (i.e., outside the furnace region, but preceding emission control). From these measurements, a DRE of 98.8 percent can be calculated. Therefore, it appears that PCB contamination in the raw MSW that was fed into this particular incinerator may have accounted for the emission of PCBs from the stack of the MSW incinerator.

PCBs can be thermolytically converted into CDFs (Choudhry and Hutzinger, 1983; U.S. EPA, 1984). This process occurs at temperatures somewhat lower than typically measured inside the firebox of an MSWI. Laboratory experiments conducted by EPA (U.S. EPA, 1984) indicate that the optimum conditions for CDF formation from PCBs are near a temperature of 675°C in the presence of 8 percent oxygen and a residence time of 0.8 seconds. This resulted in a 3 to 4 percent efficiency of conversion of PCBs into CDFs. Because 1 to 2 percent of the PCBs present in the raw refuse may survive the thermal stress imposed in the combustion zone to the incinerator (Federal Register, 1991), then it is reasonable to presume that PCBs in the MSW may contribute to the total mass of CDF emissions released from the stack of the incinerator. This is speculative, and more definitive research is needed in this area before strong conclusions can be made regarding the causes of PCB emissions during combustion.

3.5.5. Evaluation of Naturally Occurring CDD/CDFs by Examination of Sediment Core Data

In the review of these theories, a question arises as to the contribution made by combustion of synthetic organic substances produced by humans versus the contribution made by natural sources to the overall thermolytic synthesis of CDDs and CDFs. This question can be partially addressed using the results from analyses of the temporal distribution of CDDs/CDFs in sediment core samples taken from lakes located near the cradle of the U.S. industrial revolution (Czuczwa et al., 1984; Czuczwa and Hites, 1985; Czuczwa and Hites, 1986; Smith et al., 1992). Czuczwa and Hites (1985) analyzed sediment core samples taken in Lake Huron by the Great Lakes Research Station of the University of Michigan. Sedimentation rates within the core samples were determined by

using Cs-137 and Pb-210 techniques of Robbins and Edgington (1973). These rates were used as a basis of relating depth of core sample to era. CDDs/CDFs were detected in the core samples, and the results showed no appreciable degradation of CDDs/CDFs in the sediments over time. The most abundant CDDs/CDFs were OCDDs, and HpCDDs/CDFs. Analysis of depth of core sample versus era showed that the CDDs/CDFs increased steadily in concentration beginning at about 1940 and leveled off at about 1960. Comparisons were made between this trend and the total production of synthetic chlorinated organic chemicals, as well as the total volume of coal combusted for energy production. If it is theoretically possible that the combustion of coal produces air emissions of CDDs/CDFs, then this should be reflected in the sediments. The pattern of levels of CDDs and CDFs in the sediment cores seemed to track the total volume production of synthetic chloro-aromatics by the petrochemical industry in the United States, whereas the consumption of coal did not show a good correlation. Czuczwa and Hites (1985) concluded that the history of sedimentation rates of CDDs/CDFs in core samples from Lake Huron were reflective of atmospheric deposition from the combustion of synthetic chloro-aromatics, and, therefore, could only have come from the combustion of anthropogenic substances.

In a separate study, Czuczwa et al. (1984) and Czuczwa and Hites (1986) reported on the temporal variability of CDDs/CDFs in sediment core samples taken from a wilderness lake located in an uninhabited/undeveloped island (Siskiwit Lake, Isle Royale) in Lake Superior. Comparisons were made between the congener profiles found in the lake sediments to congener profiles found in urban air particulates. A near perfect correlation was found (correlation coefficient = 0.998), leading to the observation that CDDs/CDFs entered the lake system from aerial transport and deposition. The historical record of CDD/CDF concentration in the core samples showed that CDDs/CDFs were virtually absent from the sediments until around 1940, therefore ruling out any significant contribution to background from natural sources such as forest fires.

Using a similar study design, Smith et al. (1992) investigated the temporal distribution by era in sediment core samples taken from Green Lake, New York, near Niagara Falls. Green Lake is a State Park, and removed from direct discharge of

CDDs/CDFs into the system. The investigators found a similar congener profile as Czuczwa et al. (1984) and Czuczwa and Hites (1986) in the sediments, and found excellent agreement with measured deposition flux of OCDD into the lake and the concentration of OCDD in the most recent sediment layer. This supports the observation of Hites (1991) on the importance of atmospheric transport and deposition as a major pathway of entry of CDDs/CDFs into the aquatic environment. Smith et al. (1992) found that CDDs/CDFs could be detected in sediments dating back to 1860 - 1865, although concentrations were found to be low (e.g., CDDs = 7.0 ppt with 98 percent being OCDD; CDFs = 2.1 ppt with 75 percent being OCDF). These low concentrations remained essentially steady until about 1920 when concentrations significantly increased. Between 1920 and 1940, CDDs increased from about 1-10 ppt to about 250 ppt, and CDFs increased from 5 to about 100 ppt. Between 1940 and 1960, CDDs increased to about 680 ppt, and CDFs increased to about 300 ppt. From 1960 to 1980, CDDs continued to increase to approximately 950 ppt, whereas CDFs significantly declined to about 150 ppt. From the work of Czuczwa et al. (1984), Czuczwa and Hites (1986), and Smith et al. (1992), it appears that anthropogenic combustion sources, taken in their entirety, probably represent the largest mass flux of CDDs/CDFs into the environment, and that natural combustion activity (i.e., forest fires) probably is insignificant by comparison. For example, if it is assumed that the 7 ppt CDDs in sediments dating back to the 1860s is reflective more of natural sources, and if the CDDs that were found to be 950 ppt in 1980 are more reflective of human sources, then a simple comparison would indicate that anthropogenic sources may exceed natural sources by a factor of 100:1.

3.5.6. Summary of Theories of CDD/CDF Emissions

The above section discussed the likelihood that anthropogenic sources explain the bulk of CDD/CDFs currently in the environment. Still, the considerable research on the complex chemistries of combustion that transpire to ultimately yield CDDs/CDFs remains largely theoretical. The three primary theories being advanced are:

Theory 1: CDDs/CDFs present as contaminants in the combusted organic materials or that are thermally treated by a combustion process explain the emissions of CDDs/CDFs

out of the stack. It is proposed that some quantity of this initial contamination survives the thermal stress imposed by the heat of the incineration or combustion process and is subsequently emitted from the stack.

Theory 2: CDDs/CDFs are ultimately formed from the thermal breakdown and molecular rearrangement of precursor compounds. Precursor compounds are chlorinated aromatic hydrocarbons having a structural resemblance to the CDD/CDF molecule. Among the precursors that have been identified are polychlorinated biphenyls (PCBs), chlorinated phenols (CPs), and chlorinated benzenes (CBs). The formation of CDDs/CDFs is believed to occur after the precursor has condensed and adsorbed onto binding sites on the surface of fly ash particles. The active sites on the surface of fly ash particles somehow promote the chemical reactions forming CDDs/CDFs as products of this reaction, which has been observed to be catalyzed by the presence of inorganic chlorides sorbed to the particulate. Heat in a range of 250-450°C has been identified as a necessary condition for these reactions to occur, with either lower or higher temperatures inhibiting the process. Therefore, the precursor theory focuses on the region of the combustor that is downstream and away from the high temperature zone of the furnace or combustion chamber. This is a location where the gases and smoke derived from combustion of the organic materials have cooled down because of heat losses during conduction through flue ducts; passing through heat exchanger and boiler tubes to recover the heat from combustion for the co-generation of energy; after passing through some air pollution control equipment, and while convected up the stack to be discharged to the atmosphere.

Theory 3: CDDs/CDFs are synthesized *de novo* in the same region of the combustion process as described in Theory 2 (i.e., the so-called cool zone). *De novo* refers to the formation of CDDs/CDFs from organic and inorganic substrates comprised of singular or mixtures of molecules bearing little resemblance to the molecular structure of CDDs and CDFs. In broad terms, these are nonprecursors and include such diverse substances as petroleum products, chlorinated plastics (PVC), nonchlorinated plastics (polystyrene), cellulose, lignin, coke, coal, particulate carbon, and hydrogen chloride gas. Formation of CDDs/CDFs requires the presence of a chlorine donor, a molecule that partakes a chlorine atom to the predioxin molecule, and the formation and chlorination of a

chemical intermediate that is a precursor. The production of a chemical intermediate that is a dioxin precursor does not neatly differentiate Theory 2 from Theory 3, and indeed introduces some confusion into the explanation of the primary chemical events. The primary distinction is that Theory 3 begins with the combustion of diverse substances that are not defined as precursors, then the nonprecursor reacts on the carbonaceous particulate to eventually yield a chlorinated aromatic hydrocarbon that is a precursor to finally yield CDDs/CDFs. By this distinction, Theory 3 may be viewed as an augmentation to Theory 2 as explained by the initial steps in the synthesis of CDDs/CDFs.

This review has shown that all of these theories are possible and, therefore, taken as a whole, should not be seen as being mutually exclusive. One or more of these theories may act in combination during the combustion of carbonaceous matter. Theory 2 and Theory 3 require the presence of chlorine in the combustible material and in the gaseous state in the combustion plasma.

3.6. COMBUSTION AND OTHER HIGH TEMPERATURE SOURCES

A summary of the major combustion sources that produce CDDs and CDFs is presented in the following sections. The development of combustor emission estimates has been coordinated with a similar effort ongoing in EPA's Office of Air Quality Planning and Standards (OAQPS). The OAQPS effort is part of a larger EPA effort to inventory air emissions of various toxic substances. To date, OAQPS has completed emission inventories for about 20 chemicals and has completed a draft document entitled "Locating and Estimating Air Emissions from Sources of Dioxins and Furans" (U.S. EPA, 1993a). This draft OAQPS document summarizes dioxin emissions data for a variety of combustor types. OAQPS is preparing a second report (draft not yet complete) entitled "Emissions Inventory of Section 112 (c)(6) Pollutants: 2,3,7,8-TCDD, 2,3,7,8-TCDF and 2,3,7,8-TCDD Toxic Equivalents." This report will combine the emission factor information in the "Locating and Estimating" report with production values to develop actual emission rate estimates. Since the OAQPS efforts will not be completed until after this draft report is issued, it is possible that the second OAQPS report may reach somewhat different conclusions. However, the Agency is striving to coordinate these efforts and make the

outcomes as consistent as possible. Readers interested in further details about the OAQPS efforts are encouraged to contact OAQPS directly at their location in Research Triangle Park, NC.

3.6.1. Municipal Solid Waste Incineration

Characterization of the Industry

Municipal Solid Waste Incinerators (MSWI) operating in the United States can be classified into four general design categories: mass burn, modular, refuse-derived fuel, and fluidized-bed (U.S. EPA, 1992h). The first type is called mass burn because the waste is combusted without any preprocessing other than removal of items too large to go through the feed system. In a typical mass burn combustor, refuse is placed on a grate that moves through the combustor. These facilities typically range in combustion capacity from 90 to 2,700 metric tons of MSW per day. Subcategories of mass burn technologies include refractory-walled, rotary kiln, and water-wall facilities. Refractory- walled represent an older class of MSWIs generally built in the late 1970's to early 1980's that were designed to reduce the volume of waste in need of disposal by 70 to 90 percent. These facilities generally lacked boilers to recover the heat of combustion for energy purposes. In the refractory design, the MSW is delivered to the combustion chamber by a traveling grate. Combustion air in excess of stoichiometric amounts is supplied both below and above the grate. Mass burn water-wall facilities represent substantial design improvements over the refractory-walled incinerators. The water-wall refers to a series of steel tubes running vertically along the walls of the furnace. The tubes contain water, which when heated by combustion, acts as a boiler and transfers energy to produce steam. The steam is then used either to drive an electrical turbine generator or for other industrial needs. Because a secondary purpose is to generate energy to sell to a customer, significant improvements over refractory-walled MSWIs in terms of increased combustion efficiency have been fostered. The third subcategory of mass burn MSWIs is the rotary kiln. The rotary kiln lacks a traveling or reciprocating grate system to deliver MSW into the furnace. Rather it employs a water-cooled rotary combustor that is essentially a rotating combustion barrel mounted at a slight angle of decline into which the refuse is pushed by a hydraulic ram

(Donnelly, 1992). Preheated combustion air is delivered to the kiln through various portals. The slow rotation of the kiln (i.e., 10 to 20 rotations/hr) causes the MSW to tumble thereby exposing more surface area for complete burn-out. These systems are also equipped with boilers for energy recovery.

As with the mass burn type, modular incinerators also burn waste without preprocessing. Modular MSWIs consist of two combustion chambers (e.g., a primary and secondary chamber mounted in a vertical array). Modular combustors generally range in combustion capacity from 4.5 to 270 metric tons/day. One of the most common types of modular systems is the starved air (or controlled air system). In these systems, air is supplied to the primary chamber at sub-stoichiometric levels. The incomplete combustion products entrained in the combustion gases from the primary combustion chamber pass into the secondary combustion chamber where excess air is added and combustion is completed by elevated temperatures sustained by auxiliary fuel.

The third major type of MSWI technology is designed to combust refuse-derived fuel (RDF). RDF is a general term describing MSW from which relatively noncombustible items have been removed thereby enhancing the combustibility of the MSW. RDF is commonly prepared by shredding, sorting, and separating metals to create a dense MSW fuel in a pelletized form having a uniform size. RDF fuel is typically burned in a spreader stoker-type combustion chamber (Donnelly, 1992). In the United States, RDF facilities range in total combustion capacity from 227 to 2,720 metric tons/day. These MSWIs are typically steam production facilities that generate salable energy.

The fourth type of MSWI is the fluidized-bed design. In this design, the waste burns in a turbulent bed of noncombustible material, usually sand. The MSW may be fed into the incinerator either as unprocessed waste or as a form of RDF. There are two basic design concepts to the technology: (1) a bubbling-bed incineration unit and (2) a circulating-bed incineration unit. Fluidized-bed MSWIs typically have capacities ranging from 184 to 920 metric tons/day. These systems are usually equipped with boilers to produce steam.

Currently, there are about 170 to 190 MSWI facilities located in 37 states in the United States. (Berenyi and Gould, 1993; Burton and Kiser, 1993). This range in number

of facilities reflects the fact that, for any given point in time, the exact population of operating facilities is unknown. However, the best estimate is that 171 MSWI facilities are in operation (Berenyi, 1993; Berenyi and Gould, 1993). About one-half of the operating MSWIs were built since 1988 (Berenyi and Gould, 1993). The states with the greatest number of facilities are: New York (16), Florida (14), Minnesota (14), Massachusetts (8), Virginia (8), and Connecticut (7) (Berenyi and Gould, 1993). In the most recent reporting year, 1991, EPA estimated that approximately 29.35 million metric tons of MSW were combusted by all operating MSWIs; this represents approximately 17 percent of the annual generation of MSW in the United States (U.S. EPA, 1992c).

Gould (1991) estimated the average annual utilization capacity of typical MSWI designs. Utilization capacity is defined as the percentage of days a facility operates during the course of the year (U.S. EPA, 1992h). Gould (1991) estimated that existing mass burn, modular, and RDF MSWIs had average annual utilization capacities of 87.5, 84.2, and 83.3, respectively.

An estimated 85 percent of existing MSWIs are equipped with one or more air pollution control devices (APCD) to remove some class of pollutants prior to release from the stack (e.g., particulate matter, heavy metals, acid gases, and/or organic constituents) (U.S. EPA, 1992h). These APCDs include electrostatic precipitators (ESPs), fabric filters (FFs), dry sorbent injection (DSI), spray dryer adsorption (SDA), and wet scrubbers (WS). The ESP is generally used to collect and control particulate matter derived from combustion. This is accomplished by introducing a strong electrical field in the flue gas stream, which, in turn, imparts a charge to the particles entrained in the combustion gases (Donnelly, 1992). Large collection plates are given an opposite charge to attract and collect the particles. Fabric filters are also particulate matter control devices. Six- to eight-inch diameter bags made from woven fiberglass material are arranged in series. The combustion gases are forced through the tightly woven fabric. The porosity of the fabric is such that the bags act as a filter medium and retain small particles comprising the particulate matter. Dry sorbent injection is designed for the control of MSWI acid gases. DSI involves the injection of hydrated lime or soda ash into the gas stream to react with and neutralize the acid gas constituents (Donnelly, 1992). Spray dryer adsorption involves

both acid gas and particulate matter control. In a typical SDA system, hot combustion gases enter a reactor where atomized hydrated lime slurry is introduced at a controlled velocity (Donnelly, 1992). The flue gas temperature is significantly decreased, and the acid gas constituents quickly react with the reagent. The reaction evaporates the moisture to produce a dried product that is removed from the bottom of the spray dryer. In general, SDAs are used in combination with either ESPs or FFs. Greater than 95 percent reduction and control of CDDs/CDFs in MSWI emissions has routinely been achieved with FF/SDA systems (U.S. EPA, 1992h). Wet scrubber devices (WS) are designed for acid gas removal, and are more common to MSWIs in Europe than in the United States. Wet scrubber devices consist of two-stage scrubbers whereby the first stage removes HCl and the second stage removes SO_2 (Donnelly, 1992). Water is used to remove the HCl, and either caustic or hydrated lime is added to remove SO_2 from the combustion gases. Table 3-27 summarizes the current estimated distribution of operating MSWIs by design category and installed APCDs.

Estimation of MSWI Dioxin Emissions Using an Emission Factor Approach

The approach used here to estimate emissions is based on an emission factor. Emission factors are estimates of the mass of CDD/CDF emitted from the stack per kg of waste combusted. As shown in Table 3-28, these factors were estimated for each design category, multiplied by the amount of waste burned within the design category and then summed to get the total emissions.

The first step in this process is to collect emission test data representative of each design category. EPA's Office of Air Quality Planning and Standards (OAQPS) has already collected such a data set (U.S. EPA, 1993a). This summary presents emission testing for dioxin-like compounds for 30 existing MSWI facilities. These tests have been reviewed by OAQPS and determined to have used appropriate stack testing and laboratory protocols and to have been conducted under normal operating conditions. These 30 facilities represent a mix of MSWI designs and technologies as well as air pollution control devices (APCDs) in actual use, providing a basis for extrapolating to all U.S. facilities. For design

Table 3-27. Estimated Number of Operating MSWI Facilities in the United States by Design Category and Type of Air Pollution Control Device

Type of APCD	Type of MSWI Mass Burn	Type of MSWI Modular	Type of MSWI RDF	Totals by APCD
Electrostatic Precipitator (ESP)	27	12	12	51
Dry Scrubber and ESP	7	2	3	12
Fabric Filter (FF)	1	2	4	7
Dry Scrubber and FF	35	3	8	46
Wet Scrubber	3	3	1	7
Wet Scrubber and FF	0	2	0	2
Wet Scrubber and ESP	0	1	1	2
None	13	12	2	27
Unknown	2	9	6	17
Total No. of MSWIs	**88**	**46**	**37**	**171**

Sources: Kiser and Bridges (1993); Berenyi (1993); Berenyi and Gould (1993).

Table 3-28. Estimated MSW Incineration Emission Factors (EF) and Annual Emissions of Total CDD/CDFs

MSWI Technology	APCD	Avg. EF (g/kg)	# MSWI Tested	Min. EF (g/kg)	Max. EF (g/kg)	MSW Burned (kg/yr)	Emissions (g/yr)	Percent of MSW	Percent of CDD/F
Mass Burn Refractory	ESP	4.18e-05	1	9.07e-06	8.50e-05	3.10e+09	1.30e+05	10.55	72.27
Mass Burn Refractory	SD/FF	3.12e-08	1	2.68e-09	1.10e-07	1.45e+08	4.52e+00	0.49	0.00
Mass Burn Water-Wall	ESP	6.09e-07	4	1.36e-07	2.11e-06	5.26e+09	3.20e+03	17.92	1.79
Mass Burn Water-Wall	SD/ESP	4.68e-07	2	1.63e-07	1.06e-06	2.13e+09	9.97e+02	7.24	0.56
Mass Burn Water Wall	SD/FF	3.12e-08	7	2.68e-09	1.10e-07	8.47e+09	2.64e+02	28.86	0.15
Mass Burn Rotary	ESP	6.09e-07	0	1.36e-07	2.11e-06	5.04e+08	3.07e+02	1.72	0.17
Mass Burn Rotary	SD/FF	4.57e-08	2	1.50e-08	7.45e-08	1.10e+09	5.03e+01	3.76	0.03
RDF	ESP	8.86e-06	2	3.14e-07	2.17e-05	4.88e+09	4.32e+04	16.62	24.11
RDF	SD/ESP	4.35e-08	2	2.06e-08	7.25e-08	1.48e+09	6.44e+01	5.05	0.04
RDF	SD/FF	1.20e-08	3	2.38e-09	2.09e-08	9.11e+08	1.09e+01	3.10	0.01
Modular Starved Air	ESP	1.54e-06	2	1.08e-06	2.41e-06	5.15e+08	7.93e+02	1.75	0.44
Modular Starved Air	None	7.86e-07	1	7.05e-07	8.95e-07	5.02e+08	3.95e+02	1.71	0.22
Modular Excess Air	ESP	1.11e-06	2	2.85e-07	2.13e-06	3.59e+08	3.98e+02	1.22	0.22
					Total	2.94e+10	1.79e+05	100.00	100.00

Sources: U.S. EPA (1992h; 1993a)

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Table 3-28. Estimated MSW Emission Factors (EF) and Annual Emissions of Total CDD/CDFs

Description of Column Headings:

1) MSWI Technology: abbreviated technology descriptions including mass burn refractory, mass burn water-wall, mass burn rotary, refuse derived fuel, modular starved air, and modular excess air.
2) APCD: air pollution control device, including electrostatic precipitator (ESP), spray dryer combined with fabric filter (SD/FF), spray dryer combined with electrostatic precipitator (SD/ESP)
3) Avg. EF: average emission factor of g total CDD + CDF per kg municipal solid waste combusted.
4) # MSWI tested: number of municipal solid waste incinerators tested in this category.
5) Min. EF: minimum emission factor of g total CDD + CDF per kg municipal solid waste combusted.
6) Max. EF: maximum emission factor of g total CDD + CDF per kg municipal solid waste combusted.
7) MSW Burned: annual mass of municipal solid waste combusted per year based on utilization capacity.
8) Emissions: estimated annual emissions to the air of total CDD + CDF, based on average emission factor.
9) % of MSW: percent of total municipal waste combusted by this technology and air pollution control device.
10) % of CDD/F: percent of total emissions attributed to this technology and air pollution control device.

Note: Emissions data was not available for the mass burn rotary kiln equipped with ESPs. The mass burn waterwall ESP technology was judged to be most similar to rotary kiln units in terms of operating performance. Therefore, the emission factor for MBWW-ESP was applied to this class of facilities.

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categories where more than one test was available, the concentrations for each congener were averaged across tests.

The emissions data (U.S. EPA, 1993a) are presented in concentration units of nanogram of CDD/CDF per dry standard cubic meter of combustion gas (ng/dscm) corrected to 7% oxygen. Emission factors were computed for each MSWI design category by multiplying the average CDD/CDF concentration by the volume of combustion gas that is produced per kg of waste incinerated. The gas production factor was derived considering the typical heat content of the refuse as follows (Federal Register, 1987c):

1. Assume the heat content of typical MSW = 4500 B.t.u./lb of MSW.
2. Assume that 2.57E-7 dscm are produced per joule value of the MSW.
3. One joule = 9.47E-04 B.t.u.
4. One pound = 0.4536 kg

Then:

dscm/kg of MSW = (4500 B.t.u./lb) x (1 joule/9.47E-04 B.t.u) x (lb/.4536 kg) x (2.57E-07 dscm/joule)

dscm/kg of MSW = 2.69

As indicated above an emission factor was estimated for each design class and multiplied by the amount of waste burned to get the emission rate. The emission rate estimates shown in Table 3-28 reflect all congeners of CDD and CDF. These values can be converted to TEQs by applying a ratio of total CDD/CDF to TEQ. EPA has reviewed the congener-specific emissions profiles of twelve MSWI technologies and has determined that, although variable, the average ratio appears to be about 60:1 (i.e., the total mass of CDD/CDF is roughly 60 times greater than the computed TEQ) (Radian, 1994). As a measure of variability, the standard deviation from this analysis was +/- 20 from the mean ratio (i.e., a ratio of 40:1 to 80:1). As noted in Table 3-28, the total CDD/CDF mass emission from all operating 171 MSWIs is 1.8E+05 grams. The TEQ mass emission is estimated to be 3,000 grams TEQ/yr (assuming the average ratio of 60:1 for the TEQ conversion from the total CDDs/CDFs).

Discussion of Uncertainties

The procedure used to estimate national emissions of dioxin from the MSWI industry involves uncertainties that could cause the estimate to be lower or higher than the true value. The emission estimates were derived on the basis of emissions testing from 30 facilities. As discussed below much of the uncertainty revolves around the representativeness of these facilities.

- How well do the 30 facilities represent the whole population of 171 facilities in terms of technologies? The 30 facilities were selected to be representative of the range of MSWI designs and air pollution control systems. As indicated in Table 3-28, only one of the 13 design classes was not represented. Facilities of particular concern are those that use ESPs which operate in a temperature range of 200°- 400°C. As discussed in Section 3.5 these conditions can promote the formation of CDDs/CDFs. Over the past few years, some of the facilities with "hot-sided ESPs" have made changes in operating conditions or equipment to address this problem. Although, the 30 tested facilities do include some with "hot-sided ESPs" it is not clear if they are representative of current conditions at all such facilities.

- How well do the 30 facilities represent the whole population of 171 facilities in terms of timing? The emissions were largely derived from stack tests conducted during the period 1988 to 1991. Since 1991, new facilities may have become operational or changes may have been made to existing ones. Therefore emissions today may be somewhat lower, reflecting continued improvements in combustor design.

- For individual facilities, how representative are emission tests of long term performance? The average emissions from a single facility are typically derived from 3 - 4 days of testing over the year. It is not known to what extent such short-term testing may truly reflect long-term emissions, e.g., through the life of the facility. Most stack testing data were collected while the MSWI was operating according to design specifications, e.g., under normal operating conditions. Using these data would not reflect any additional

emissions that may occur during upsets in the combustion zone, poor operations, equipment malfunctions, or degradation in the effectiveness of the pollution control systems.

- How accurate is the approach used to convert stack concentrations to emission factors? As discussed earlier in this section, the approach used to convert concentration in the combustion gas to an emission factor is based on an assumption that 2.69 dscm of combustion gas are produced per kg of MSW burned. This quantity is variable among facilities and is dependent on such factors as the temperature of combustion, the amount of air supplied to combustion chamber in excess of stoichiometric requirements, the moisture of the feed material being burned, and the heat value of the feed material being combusted. For some technologies with relatively high amounts of excess air delivered to the combustion chamber, the gas volume may be as high as 5.0 - 6.0 dscm/kg.

- How accurate is the procedure used to convert total CDD/CDF emissions to Toxic Equivalents (TEQs)? The conversion ratio was based on a review of emissions from 12 MSWIs. In actuality, the ratio of total CDD/CDF to TEQ is variable from one facility to another. It is influenced by the composition of the MSW and the operating conditions of the combustor. It is not known how representative the generic ratio of 60:1 is of dioxin emissions from all existing MSWIs.

Although MSWIs have the strongest emission data base of all combustion sources evaluated in this document, it still must be considered uncertain for the reasons stated above. Therefore, the estimated emission factors are given a "medium" confidence rating.

The amount of MSW that is annually combusted by various MSWI technologies (see Table 3-28) is given a "high" confidence rating. These estimates are based on a recently conducted and comprehensive survey (U.S. EPA, 1992h). Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual emissions (3,000 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 1,300 to 6,700 g TEQ/yr.

EPA Regulatory Activities

EPA will soon propose revised emission standards for all existing and new MSWIs with unit capacities greater than 30 metric tons per day. Once these standards have been promulgated, and the States have fully enforced the emission limits, then EPA expects to reduce the national emissions of dioxin emissions from all existing MSWIs by about 99 %. All existing facilities combined should then be emitting about 30 g TEQ/yr. Full implementation and enforcement of the rules should be achieved by the year 2000. As the compliance date approaches and facilities are upgraded, EPA expects that emissions from these facilities will decline significantly from current levels.

Estimated CDD/CDFs in MSWI Ash

An estimated 7 million metric tons of total ash (bottom ash plus fly ash) are generated annually by MSWIs (telephone conversation between J. Loundsberry, U.S. EPA Office of Solid Waste, and L. Brown, Versar Inc., on February 24, 1993). U.S. EPA (1991b) indicates that 2.8 to 5.5 million tons of total ash are produced from MSWIs with fly ash comprising 5 to 15 percent of the total. U.S. EPA (1990c) recently reported the results of analyses of MSWI ash samples for CDDs and CDFs. Ashes from five state-of-the-art facilities located in different regions of the United States were analyzed for all 2,3,7,8-substituted CDDs and CDFs. The TEQ levels in the ash (fly ash mixed with bottom ash) ranged from 106 ng/kg to 466 ng/kg with a mean value of 258 ng/kg. CDD/CDF levels in fly ash are generally much higher than in bottom ash. For example, Fiedler and Hutzinger (1992) report levels of 13,000 ng TEQ/kg in fly ash. Multiplying the mean TEQ total ash concentration by the estimated volume of MSWI ash generated annually (7 million metric tons) yields an estimated annual TEQ in MSWI ash of 1,800 g TEQ/yr.

The total ash generation estimate is given a "medium" confidence rating since it is based on an expert opinion and is about twice as high as earlier published estimates. The emission factor is given a "medium" confidence rating because it is based on direct measurements at five facilities, although these five facilities may not be representative of all technologies in the United States. Based on these confidence ratings, the estimated

range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual emissions (1,800 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 810 to 4,000 g TEQ/yr.

Each of the five facilities sampled in U.S. EPA (1990c) had companion ash disposal facilities equipped with leachate collection systems or some means of collecting leachate samples. Leachate samples were collected and analyzed for each of these systems. Detectable levels were only found in the leachate at one facility (TEQ = 3 ng/l); the only detectable congeners were HpCDDs, OCDD, and HpCDF.

3.6.2. Hazardous Waste Incineration

EPA estimates that there are 190 Hazardous Waste Incinerators (HWIs) in the United States. This total includes both operating facilities and facilities that are not operating but have filed an application with EPA (Helble, 1993). The four principal technologies employed for the combustion of hazardous waste in the United States are: liquid injection, rotary kiln, fixed hearth and fluidized-bed incinerators (Dempsey and Oppelt, 1993). Liquid injection incinerators are designed to burn pumpable liquid hazardous waste. These incinerators are typically simple refractory-lined cylinders (either horizontally or vertically aligned) equipped with one or more waste burners. The liquid waste is injected into the combustion chamber through an atomizer, and the liquid droplets are exposed to high temperatures in suspension. Rotary kiln incinerators are the more common design. They have the added versatility of being able to combust hazardous waste in any physical form (i.e., liquid, semi-solid, or solid). The rotary kiln is a horizontal cylinder lined with refractory material. Rotation of the cylinder on a slight slope provides for transport of the waste through the kiln, as well as enhanced mixing and exposure to the heat of combustion. The combustion gases emanating from the kiln are usually passed through a high temperature afterburner chamber to more completely destroy organic pollutants arising from combustion. Fixed hearths, the third principal hazardous waste incineration technology, are starved air or pyrolytic incinerators. These are two-stage combustion units. Waste is ram-fed into the primary chamber and incinerated at about 50

to 80 percent of stoichiometric air requirements. The resulting smoke and pyrolytic combustion products are then passed though a secondary combustion chamber where relatively high temperatures are maintained by the combustion of auxiliary fuel. Oxygen is introduced into the secondary chamber to promote complete thermal oxidation of the organic molecules entrained in the gases. The fourth hazardous waste incineration technology is the fluidized-bed incinerator. This technology is similar in design to that employed in MSW incineration. (See Section 3.6.1).

Dempsey and Oppelt (1993) summarized the results of EPA-sponsored stack testing at six full-scale HWIs, three PCB incinerators, and one incinerator burning PCP waste. CDD/CDFs were detected at all three PCB incinerators with TEQ emission rates ranging from 0.3 to 1.63 ng TEQ/dscm (@ 7 percent oxygen). CDD/CDFs were detected at three of the HWIs with TEQ emission rates ranging from 0.57 to 17.7 ng TEQ/dscm (@ 7 percent oxygen).

Helble (1993) reviewed recent data from trial burn reports on CDD/CDF emissions from 15 HWIs. CDD/CDFs were detected in the stack emissions of 11 of the 15 facilities at total CDD/CDF emission rates ranging from 0.1 to 1,600 ng/dscm (@ 7 percent oxygen) with most facilities between 1 and 100 ng/dscm. Based on his evaluation of the emissions data, Helble (1993) concluded that the CDD/CDFs observed in emissions from HWIs are formed catalytically under low temperature conditions either through catalytic chlorination or through catalytic condensation of dioxin-like precursors such as chlorobenzenes and PCBs.

Emission factors are estimated based on the results of the emission tests reported by Helble (1993). Homologue-specific emissions data, waste feed rates, and stack flow rates (dscm @ 7 percent oxygen) were available for six of the HWIs evaluated by Helble (1993). From these data, total CDD/CDF emission factors were calculated for each facility (range: 10 to 6,830 ng/kg of waste feed; mean: 1,550 ng/kg of waste feed). For those facilities with more than one test run reported, the total CDD/CDF emission rates for the individual runs were averaged to obtain a facility average emission rate. These total CDD/CDF emission factors were converted to TEQ emission factors using a conversion factor of 1.75 ng TEQ/ng of total CDD/CDF that was developed by EER, Inc. for EPA's

Office of Solid Waste (EER, 1993). The resulting mean TEQ emission factor is 27.2 ng TEQ/kg waste feed (range = 0.18 to 119 ng TEQ/kg waste feed).

Dempsey and Oppelt (1993) estimate that between 216 and 249 million metric tons of hazardous waste were generated in 1987 (the year for which the most comprehensive data on waste management are available). Of this total amount, Dempsey and Oppelt (1993) estimate that between 1.0 and 1.3 million metric tons of hazardous waste were incinerated. Based on an estimated 1.3 million metric tons of hazardous waste incinerated per year in the United States and the mean emission factor derived above, it is estimated that 2,000 grams CDD/CDF per year and 35 grams TEQ/yr are emitted from HWIs.

A "low" confidence rating is ascribed to the emission factors derived above because stack test data were available for only 6 of the 190 HWIs in the United States and the stack test data used represent only one hazardous waste technology (rotary kiln). The "production" estimate has been assigned a "medium" confidence rating because it is based on a thorough review of the various studies and surveys which have been conducted in recent years to assess the quantity and types of hazardous waste generated in the United States, as well as the quantities and types of wastes being managed by various treatment, storage and disposal facilities. Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual TEQ emissions (35 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 11 to 110 g TEQ/yr.

3.6.3. Medical Waste Incineration

Buonicore (1992b) has reviewed the primary incineration technologies used to burn medical and pathological wastes in the United States. These medical waste incinerations (MWI) fall within three broad technology categories: retort, controlled-air, and rotary kiln. Retort incinerators are multiple chamber combustors characteristic of the "older" existing technology. The medical waste is fed into a primary combustion chamber, and the gases from combustion are passed into a secondary chamber. In the secondary chamber,

secondary auxiliary fuel is burned to sustain higher temperatures and to more completely burn the organic pollutants entrained in the combustion gas from primary combustion. Combustion air, 100 to 300 percent in excess of stoichiometric requirements, is usually added to the secondary chamber. Gases exiting the secondary chamber are directed to an incinerator stack. The second principal technology is the controlled-air incinerator. This is the most common technology used to incinerate hospital/medical waste and is often referred to as modular incineration. Like retort incinerators, combustion occurs in two stages. Medical waste is fed into a primary combustion chamber where air is delivered at less than stoichiometric requirements. Under these conditions, the waste is pyrolyzed and volatile compounds are released. A secondary chamber is located on top of the primary unit. Auxiliary fuel is added to sustain high temperatures in a controlled-air environment. These systems are usually automated with computer-directed controllers that are integrated with a thermocouple. Thus, the quality of combustion is superior to the retort technology. The third type of MWI is the rotary kiln. This is the same technology as employed in both municipal and hazardous waste incineration. (See Sections 3.6.1 and 3.6.2).

EPA has estimated that about 4.3 million metric tons (4.76 million short tons) of hospital/medical wastes are generated annually in the United States (U.S. EPA, 1991d). Table 3-29 summarizes the types and number of facilities that generate medical waste, and their corresponding annual generation rate of medical wastes. There are about 6,700 MWIs operating nationwide combusting approximately 3.72 million metric tons of medical waste annually (U.S. EPA, 1991d). Table 3-30 summarizes the estimated population of MWI currently operating in the United States.

CDDs and CDFs have been identified in the stack gas emissions of MWIs located at hospitals in the United States (U.S. EPA, 1993a). Although operating on a smaller-scale, the mechanism of CCD/CDF formation in hospital waste incineration is similar to that described for MSWI in Section 3.6.1. To support future rulemaking, EPA has developed a summary of annual emissions of dioxin from all existing hospital waste incinerators operating in the United States (U.S. EPA, 1991e). This summary represents an analysis and review of dioxin emissions measured at the stack from six MWIs (Radian, 1991a;

Table 3-29. Estimated Number and Type of Facilities and Quantities of Medical Waste Generated Annually in the United States

Facility Type	No. of Facilities	Infectious Waste(tons/yr)	Medical Waste (tons/yr)
Hospitals	7,000	360,000	2,400,000
Laboratories	7,200	25,900	173,000
Clinics	41,300	26,300	175,000
Physician offices	180,000	35,200	235,000
Dentist offices	98,000	8,700	58,000
Veterinarians	38,000	4,600	31,000
Care facilities	42,700	31,100	207,000
Blood banks	900	4,900	33,000
Funeral homes	21,000	900	138,000
Industry units	221,700	1,400	9,000
Fire and Rescue	7,200	1,600	11,000
Prisons	4,300	3,300	22,000
Police	13,100	<100	<1,000
Animal shelters	4,500	----------	72,000
Totals	686,900	504,000	3,565,000

Source: U.S. EPA (1991d)

Table 3-30. Medical Waste Incineration Facilities Operating in the United States

MWI Facilities	Estimated Number of MWIs	Avg. MWI Capacity (kg/hr)
Hospitals	3,150	124
Laboratories	500	153
Veterinary hospitals	550	55
Nursing homes	500	76
Crematories/funeral homes	1,200	82
Animal shelters	500	90
Commercial facilities	150	535
Other/unidentified	150	75
Total	6,700	

Source: U.S. EPA (1991d)

1991b; 1991c; McCormack, 1990; Lew et al., 1988; Lew et al., 1989). From these reports, EPA derived an average emission factor of total amount of dioxin released to the air per kg of medical waste combusted in a typical MWI (g total CDD/CDF per kg waste), based largely on uncontrolled emissions (U.S. EPA, 1993a). The average uncontrolled emission factor of total CDD/CDF is 8.53E-05 g/kg (U.S. EPA, 1993a). This factor can be compared with the average controlled emission factor of total CDD/CDF of 4.46E-06 g/kg from one facility equipped with acid gas controls and a fabric filter (U.S. EPA, 1993a). The ratio of controlled to uncontrolled emissions is a factor of 1:20. Table 3-31 summarizes the emission factors developed for this analysis.

In computing an estimate of national emissions of dioxin from 6,700 existing MWIs, EPA applied an average emission factor developed for uncontrolled MWIs. Uncontrolled emissions are defined as emissions from a MWI facility not equipped with add-on air pollution control devices (APCD) (e.g., electrostatic precipitator, scrubber, fabric filter, etc.). However, MWIs are modular designs consisting of both a primary and secondary combustion chamber. The purpose of the secondary combustion chamber is the continued destruction of organic compounds emanating from the primary chamber. Therefore MWIs are not actually totally uncontrolled. EPA expects that the majority of the existing MWIs are uncontrolled with respect to dioxin control measures (U.S. EPA, 1991e). EPA believes that the selection of an average emission factor derived from uncontrolled emissions currently represents the most accurate means of estimating the magnitude of potential dioxin release from all 6,700 operating MWIs (U.S. EPA, 1991e).

In order to estimate national emission of total dioxin to the air from all operating facilities, EPA categorized the population of MWIs according to the operating duty, the size of the combustor, and the amount of medical or pathological waste combusted per year. Table 3-32 summarizes the estimate of total dioxin emitted (g/yr) from all operating MWIs in the United States according to this disaggregation. Emissions to air of total CDD/CDF (i.e., tetra-chlorinated through octa-chlorinated compounds) from approximately 6,700 existing medical waste incinerators are estimated to be 3.18E+05 grams/yr. This emission estimate was derived from tests conducted at six facilities (considered to be representative of the major design types), extrapolating average emissions nationwide

Table 3-31. CDD/CDF Emission Factors for Uncontrolled Medical Waste Incinerators Operating in the United States

Congener or Congener Group	Average Emission Factor (g/kg)	Minimum Emission Factor (g/kg)	Maximum Emission Factor (g/kg)
2,3,7,8-TCDD	5.64 E-8	6.37 E-10	4.47 E-7
Other TCDD	8.86 E-7	1.91 E-9	8.38 E-6
PeCDD	2.03 E-6	3.21 E-8	1.34 E-5
HxCDD	4.23 E-6	1.29 E-7	2.13 E-5
HpCDD	6.35 E-6	1.19 E-7	2.67 E-5
OCDD	4.29 E-6	6.63 E-8	2.61 E-5
2,3,7,8-TCDF	2.60 E-7	5.26 E-9	1.65 E-6
Other TCDF	6.63 E-6	6.62 E-8	4.79 E-5
PeCDF	1.37 E-5	2.53 E-7	1.22 E-4
HxCDF	1.86 E-5	2.17 E-7	1.06 E-4
HpCDF	1.68 E-5	1.49 E-7	1.30 E-4
OCDF	1.19 E-5	6.56 E-8	5.45 E-5
Total CDD/CDF	8.53 E-5	1.52 E-6	3.93 E-4

Source: U.S. EPA (1993a).

Note: Emission factors (grams dioxin/kg waste) were derived as the average and range from six tested facilities.

Table 3-32. Estimated Annual Emission of Total CDD/CDFs (g/yr) from Incineration of Medical Waste

Type of Waste	Type of MWI	Number of MWIs	Waste Burned (kg/yr)	CDD/CDF Emission Factor (g/kg)	CDD/CDF Emission (g/yr)
Pathological	Batch Fed	1,200	1.225 E+8	8.53 E-5	1.04 E+4
	Intermittent	1,598	4.297 E+8	8.53 E-5	3.67 E+4
Mixed Medical	Batch-small	335	2.674 E+8	8.53 E-5	2.28 E+4
	Intermittent - small	2,287	6.150 E+8	8.53 E-5	5.25 E+4
	Intermittent -medium	766	7.480 E+8	8.53 E-5	6.38 E+4
	Intermittent - large	178	4.345 E+8	8.53 E-5	3.71 E+4
	Semicontinuous - large	182	2.942 E+8	8.53 E-5	2.51 E+4
	Continuous - large	154	8.131 E+8	8.53 E-5	6.94 E+4
	Totals	6,700	3.724 E+9		3.18 E+5

Sources: U.S. EPA (1991d; 1991e; 1991f; 1993)

Description of terminology:

Pathological Batch Fed: Controlled-air MWI; operates 3,520 hrs/yr with capacity of 226.8 kg/hr; operational at hospitals, animal shelters, nursing homes, laboratories, and veterinary hospitals.
Pathological Intermittent: Controlled-air MWI; operates 2,964 hrs/yr with capacity of 90.7 kg/hr; operational at funeral homes/crematories.
Mixed Medical Waste:

- Intermittent: Controlled-air MWI; small: operates 2,964 hr/yr with capacity of 90.7 kg/hr; medium: operates 3,588 hr/yr with capacity of 272.16 kg/hr; large: operates 3,588 hr/yr with capacity of 680 kg/h; operational at hospitals, animal shelters, nursing homes, laboratories, and veterinary hospitals.
- Batch fed: Controlled-air MWI; small: operates 3,520 hr/yr with capacity of 226.8 kg/hr; operational at hospitals.
- Semicontinuous: Controlled-air MWI;large: operates 3,564 hr/yr with capacity of 453/6 kg/hr; operates at hospitals and laboratories.
- Continuous: Controlled-air MWI; large: operates 7,760 hr/yr with capacity of 680.4 kg/hr; operated by commercial medical waste incinerators.

using the amount of waste burned in each of the design classes.

For purposes of deriving an estimate of emissions in terms of TEQ, it is necessary to convert the total CDD/CDF emission into an estimated TEQ emission. This is done by assuming a ratio of TEQ to total CDD/CDF using existing data on emissions from existing facilities. The State of California Air Resources Board (CARB) has stack tested a number of hospital waste incinerators in southern California (CARB, 1990a). Congener-specific emissions of CDD/CDFs were measured in the stack gas emissions of seven facilities. From these data, the ratio of TEQ to total CDD/CDF is 0.016 as an overall average of five tested facilities. Multiplication of the annual emissions of CDD/CDF (in grams per year) by this ratio yields an estimate of 5,100 g TEQ emitted (grams per year) for all existing MWIs in the United States.

U.S. EPA (1993a) reports emissions testing at a number of controlled-air medical waste incinerators with a variety of emission controls. These tests yielded a lower range of emission factors. Based on these data, it appears possible that the national releases from medical waste incinerators could be much lower than the "average" value identified above. It is difficult to say how much lower, since it is unknown how representative these tested facilities are of all 6,700 facilities in the United States.

A "medium" confidence rating is assigned to the estimate of amount of hospital waste burned since it is based on a detailed study specific to the United States; however, the large number of these facilities makes it difficult to estimate precisely. The emission factor used to extrapolate to a national basis is given a "low" confidence rating, because the average was derived from the stack sampling at a small sample of the large numbers of MWI facilities (6 of 6,700). Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (5,100 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 1,600 to 16,000 g TEQ/yr.

3.6.4. Kraft Black Liquor Recovery Boilers

In 1987, the U.S. EPA stack tested three kraft black liquor recovery boilers for the emission of dioxin in conjunction with the National Dioxin Study (U.S. EPA, 1987). These boilers are associated with the production of pulp in the making of paper using the Kraft process. In this process, wood chips are cooked in large vertical vessels called digesters at elevated temperatures and pressures in an aqueous solution of sodium hydroxide and sodium sulfide (Someshwar and Pinkerton, 1992). Wood is broken down into two phases: a soluble phase containing primarily lignin, and an insoluble phases containing the pulp. The spent liquor (called black liquor) from the digester contains sodium sulfate and sodium sulfide that the industry finds beneficial in recovering for reuse in the Kraft process. In the recovery of black liquor chemicals, weak black liquor is first concentrated in multiple-effect evaporators to about 65 percent solids. The concentrated black liquor also contains 0.5 to 4 percent chlorides by weight (U.S. EPA, 1987). Recovery of beneficial chemicals is accomplished through combustion in a Kraft black liquor recovery furnace. The concentrated black liquor is sprayed into a furnace equipped with a heat recovery boiler. The bulk of the inorganic molten smelt that forms in the bottom of the furnace contains sodium carbonate and sodium sulfide in a ratio of about 3:1 (Someshwar and Pinkerton, 1992). The combustion gas is usually passed through an electrostatic precipitator that collects particulate matter prior to being vented out the stack. The particulate matter can be processed to further recover and recycle sodium sulfate.

The three sites that were stack tested by EPA (U.S. EPA, 1987) were judged to be typical of Kraft black liquor recovery boilers. The following emission factors of dioxin were derived from the stack emissions data: average CDD/CDF = 9.34E-03 μg/kg (range: 4.88E-03 to 1.67 E-02 μg/kg), and average TEQ = 9.71E-05 μg/kg (range: 3.33E-05 to 2.06E-04 μg/kg). A "medium" confidence rating is ascribed to these emission factors because the emission factors were derived from the stack testing of three Kraft black liquor recovery boilers that were judged to be fairly representative of technologies used at Kraft pulp mills in the U.S.

In 1989, EPA estimated that approximately 28.2 million metric tons of black liquor solids were burned in Kraft black liquor recovery boilers in the U.S. (U.S. EPA, 1992g).

This production estimate was given a confidence rating of "high" because it is based on a recent industry-wide survey conducted by EPA. Assuming this is the quantity of black liquor that is combusted each year, then it is estimated that 264 grams of CDD/CDF and 2.7 grams of TEQ are emitted to the U.S. atmosphere annually. Based on the confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual TEQ emissions (2.7 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 0.9 to 4.3 g TEQ/yr.

As discussed in Section 3.2, approximately 500 million dry kg of pulp and paper mill wastewater sludge were incinerated in 1990 by facilities employing chlorine bleaching of pulp (U.S. EPA, 1993e). However, insufficient data are currently available to estimate emission factors for dioxin-like compounds from pulp and paper mill incinerators. As discussed in Section 3.2, EPA proposed control technology standards that address CDD/CDF emissions for non-combustion pulp and paper mill sources in December 1993 (Federal Register, 1993a) and will propose control technology standards for combustion sources by October 1994 (U.S. EPA, 1992d).

3.6.5. Sewage Sludge Incineration

Brunner (1992) reviewed the four principal combustion technologies used to incinerate sewage sludge in the U.S.: multiple-hearth incinerator, fluidized-bed incinerator, electric furnace, and cyclone furnace. All of these technologies are "excess-air" processes (i.e., they combust sewage sludge with oxygen in excess of theoretical requirements). Of the four types of technologies, multiple-hearth incinerators are the most common. They constitute approximately 60 percent of the 199 existing sewage sludge incineration facilities operational in the U.S. (Federal Register, 1993b). The furnace consists of refractory hearths arranged vertically in series, one on top of the other. Dried sludge cake is fed to the top hearth of the furnace. The sludge is mechanically moved from one hearth to another through the length of the furnace. Moisture is evaporated from the sludge cake in the upper hearths of the furnace. The center hearths are the burning zone to the furnace where gas temperatures reach 871°C. The bottom hearths are the burn-out zone where

the sludge solids become ash. A waste-heat boiler is usually included in the burning zone where steam is produced to provide supplemental energy at the sewage treatment plant. Air pollution control measures typically include a wet scrubber system for particulate matter control (U.S. EPA, 1987).

The fluidized-bed incinerator is a cylindrical refractory-lined shell with a steel plate structure that supports a sand bed near the bottom of the furnace (Brunner, 1992). Air is introduced through openings in the bed plate supporting the sand. This causes the sand bed to undulate in a turbulent air flow, hence the sand appears to have a fluid motion when observed through furnace portals. Sludge cake is added to the furnace at a position just above this fluid motion of the sand bed. The fluid motion promotes mixing in the combustion zone. Sludge ash exists the furnace with the combustion gases, therefore air pollution control systems typically consist of high-energy venturi scrubbers.

Electric furnaces are sometimes called infrared furnaces (Brunner, 1992). This incineration system consists of a long rectangular refractory-lined chamber. A belt conveyer system moves the sludge cake through the length of the furnace. To promote combustion of the sludge, supplemental heat is added by electric infrared heating elements within the furnace that are located just above the travelling belt. Electric power is required to initiate and sustain combustion.

Cyclonic furnaces consist of a refractory-lined cylindrical shell with a domed top (Brunner, 1992). Air is blown in at tangential burner ports on the furnace shell which causes a violent swirling pattern. This motion promotes good mixing of combustion air with the sludge feed. Sludge is fed into the furnace chamber by screw conveyor. Combustion gases exit at the top of the swirling vortex at the top of the furnace dome.

EPA has confirmed that dioxin can be emitted from sewage sludge incineration based on the testing of three multiple-hearth sewage sludge incinerators (U.S. EPA, 1987). Emission factors for dioxin were developed from these data. The average emission factor of CDD/CDF was estimated to be 1.26E+00 μg/kg of dry sewage sludge (range: 8.80E-02 to 3.37E+00 μg/kg). The average emission factor for TEQ was estimated to be 2.69E-02 μg/kg of dry sewage sludge (range: 1.17E-03 to 3.04E-02 μg/kg) assuming perfect congener distribution within the total CDD/CDFs measured.

In 1992, approximately 199 sewage sludge incineration facilities combusted about 0.865 million metric tons of dry sewage sludge (Federal Register, 1993b). Given this mass of sewage sludge incinerated/yr, the best estimates of emissions to air are 1,090 grams of CDD/CDF per year and 23 grams TEQ per year from all sewage sludge incineration facilities.

A "medium" confidence rating is ascribed to the emission factors because they were developed from the stack testing of three multiple hearth incinerators. Although multiple hearth incinerators are the dominant technology in use in the U.S. today, some uncertainty exists as to the representativeness of these derived emission estimates to possible emissions from other sewage sludge incineration technologies. The production estimate is assigned a "high" confidence rating because it is based on an extensive EPA survey to support rulemaking activities. Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual emissions (23 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 10 to 52 g TEQ/yr.

3.6.6. Primary Nonferrous Metal Smelting/Refining

Nonferrous metals include aluminum, copper, nickel and magnesium. Insufficient information is available for evaluating CDD/CDF emissions, if any, from primary smelting/refining of nonferrous metals in the United States. However, several European investigators have investigated the presence of CDD/CDFs at some facilities in this industry.

Oehme et al. (1989) reported that the production of magnesium leads to the formation of CDDs and CDFs. Oehme et al. (1989) estimated that 500 g of TEQ are released in wastewater to the environment and 6 g TEQ are released to air annually from a magnesium production facility studied in Norway; CDFs predominated with a CDF to CDD concentration ratio of 10 to one. The magnesium production process involves a step in which $MgCl_2$ is produced by heating MgO/coke pellets in a pure chlorine atmosphere to about 700 to 800°C. The $MgCl_2$ is then electrolyzed to metallic magnesium and Cl_2. The

Cl_2 excess from the $MgCl_2$ process and the Cl_2 formed during electrolysis is collected by water scrubbers and discharged to the environment.

Oehme et al. (1989) also report that certain primary nickel refining processes generate CDDs and CDFs, primarily CDFs. Although the current low temperature process used at the Norwegian facility studied is estimated to release only 1 g TEQ per year, a high temperature $NiCl_2$/NiO conversion process that had been used for 17 years at the facility is believed to have resulted in much more significant releases based on the ppb levels of CDFs detected in aquatic sediments downstream of the facility (Oehme et al., 1989).

Lexen et al. (1993) reported that samples of filter powder and sludge from a lagoon at the only primary aluminum production plant in Sweden showed no or little CDD/CDF.

3.6.7. Secondary Nonferrous Metal Smelting/Refining

Secondary smelters/refiners are establishments primarily engaged in the recovery of nonferrous metals and alloys from new and used scrap and dross. The principal metals of this industry both in terms of volume and value of product shipments are aluminum, copper, lead, zinc, and precious metals (U.S. DOC, 1990a). Scrap metal and metal wastes may contain organic impurities such as plastics, paints, and solvents. Secondary smelting/refining processes for some metals (e.g., aluminum, copper, and magnesium) utilize chemicals such as NaCl, KCl, and other salts. The combustion of these impurities and chlorine salts in the presence of various types of metal during reclamation processes can result in the formation of CDDs and CDFs as evidenced by the detection of CDDs and CDFs in the stack emissions of secondary aluminum, copper, and lead smelters (Aittola et al., 1992; U.S. EPA, 1987; 1994b; 1994c; 1994d).

3.6.7.1 *Secondary Aluminum Smelters and Refiners*

Levels of 2,3,7,8-TCDF in stack gas from an aluminum reclamation facility in the Finnish city of Vyborg have been measured at approximately 43 ng/m^3 (Aittola et al., 1992). However, no studies of CDD/CDF emissions from secondary aluminum smelters located in the United States have been reported. Aluminum is processed at more smelters than any other nonferrous metal in the United States. Also more aluminum undergoes

secondary smelting than any other nonferrous metal. An estimated 1.7 million metric tons of aluminum were produced by secondary smelters in 1987 in the United States (U.S. DOC, 1990a).

3.6.7.2 *Secondary Copper Smelters and Refiners*

Stack emissions of CDD/CDFs from a secondary copper smelter were measured by EPA during the National Dioxin Study (U.S. EPA, 1987). The tested facility recovers copper and precious metals from copper and iron-bearing scrap. The copper and iron-bearing scrap are fed in batches to a cupola blast furnace, which produces a mixture of slag and black copper. Four to five tons of metal-bearing scrap were fed to the furnace per charge, with materials typically being charged 10 to 12 times per hour. Coke was used to fuel the furnace, and represented approximately 14 percent by weight of the total feed. During the stack tests, the feed consisted of electronic telephone scrap and other plastic scrap, brass and copper shot, iron-bearing copper scrap, precious metals, copper bearing residues, refinery by-products, converter furnace slag, anode furnace slag, and metallic floor cleaning material. Oxygen enriched combustion air for combustion of the coke was blown through tuyeres at the bottom of the furnace. At the top of the blast furnace were four natural gas-fired afterburners to aid in completing combustion of the exhaust gases. Particulate emissions were controlled by fabric filters, and the flue gas then was discharged into a common stack. The estimated emission factors derived for this one site are: CDD/CDF = 3.89E+04 ng/kg of scrap metal smelted (range: 3.31E+04 to 4.05E+04 ng/kg); TEQ = 7.79E+02 ng/kg of scrap metal smelted (range: 7.64E+02 to 1.04E+03 ng/kg).

More than 0.3 million metric tons of copper were produced by the 24 secondary copper smelters operating in the United States in 1987 (U.S. DOC, 1990a). If the emission rates derived above are assumed to be representative of all secondary copper smelters, then the best estimate of annual air emission of CDD/CDF released by secondary copper smelting operations in the United States is 1.17E+04 grams per year and the best estimate of TEQ emission is 2.34E+02 grams per year. A "high" confidence rating is given to the production estimate because it is based on reliable data from the U.S. 1987

Census of Manufactures. A "low" confidence rating is given to the emission estimates since they are based on direct measurements at only one U.S. copper smelter. Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (234 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 74 to 740 g TEQ/yr.

3.6.7.3 *Secondary Lead Smelters and Refiners*

The secondary lead smelting industry produces elemental lead through the chemical reduction of lead compounds (obtained primarily from scrap motor vehicle lead-acid batteries) in a high temperature furnace (1,200 to 1,260 degrees C). Smelting is performed in reverberatory, blast, rotary, or electric furnaces. Blast and reverberatory furnaces are the most common types of smelting furnaces used by the 23 facilities that comprise the current secondary lead smelting industry in the United States. Of the 45 operating furnaces at these 23 facilities, 15 are reverberatory furnaces, 24 are blast furnaces, 5 are rotary furnaces, and 1 is an electric furnace. The one electric furnace and 11 of the 24 blast furnaces are co-located with reverberatory furnaces and most share a common exhaust and emissions control system (U.S. EPA, 1994a). Furnace charge materials consist of lead-bearing raw materials, lead-bearing slag and drosses, fluxing agents (blast and rotary furnaces only), and coke. Fluxing agents consist of iron, silica sand, and limestone or soda ash. Coke is used as fuel in blast furnaces and as a reducing agent in reverberatory and rotary furnaces. The PVC plastic seperators in the batteries are the primary source for HCl emissions from the smelters. However, the fluxing agents used at blast and rotary furnaces also react with chlorine to form calcium chloride or sodium chloride therby reducing HCl emissions from these furnaces relative to reverberatory furnaces. Organic emissions from co-located blast and reverbertory furnaces are more similar to the emissions of a reverberatory furnace than the emissions of a blast furnace (U.S. EPA, 1994a).

The total annual production capacity of the U.S. lead smelting industry is 1.36 million metric tons. Blast furnaces not co-located with reverberatory furnaces account for

21 percent of capacity (or 0.28 million metric tons). Reverberatory furnaces and blast and electric furnaces co-located with reverberatory furnaces account for 74 percent of capacity (or 1.01 million metric tons). Rotary furnaces account for the remaining 5 percent of capacity (or 0.07 million metric tons). Actual production volume statistics by furnace type are not available. However, if it is assumed that the total actual production volume of the industry (0.86 million metric tons in 1990) is reflective of the production capacity breakdown by furnace type, then the estimated actual production volumes of blast furnaces (not co-located), reverberatory and co-located blast/electric and reverberatory furnaces, and rotary furnaces are 180, 637, and 43 thousand metric tons, respectively (U.S. EPA, 1994a).

CDD/CDF and TEQ emission factors can be estimated for lead smelters based on the results of emission tests recently performed by EPA at three smelters (a blast furnace, a co-located blast/reverberatory furnace, and a rotary kiln furnace) (U.S. EPA, 1992i; 1993g; 1993h). The air pollution control systems at the three tested facilities consisted of both baghouses and scrubbers. Congener-specific measurements were made at the exit points of both APCD exit points at each facility. Although all 23 active smelters employ baghouses, only 9 employ scrubber technology. Facilities that employ scrubbers account for 14 percent of the blast furnace (not co-located) production capacity, 52 percent of the reverberatory and co-located furnace production capacity, and 57 percent of the rotary furnace production capacity. From the reported data, TEQ emission factors (ng TEQ/kg lead recovered) for each of the three furnace configurations are presented below as a range reflecting the presence or absence of a scrubber.

- Blast furnace: 0.63 to 8.31 ng TEQ/kg lead
- Reverberatory/co-located furnace: 0.10 to 0.77 ng TEQ/kg lead
- Rotary furnace: 0.28 to 0.21 ng TEQ/kg lead

If it is assumed that these emission rate ranges are representative of the range of emission rates at the non-tested facilities with the same basic furnace configuration and presence or absence of scrubbers, then combining these emission rate ranges with the

estimates derived above for annual secondary lead production volumes yields a total industry-wide estimated emission to air of 1.6 g of TEQ. The estimated contributions to this total for each furnace configuration are:

- Blast furnaces with scrubbers: 0.02 g TEQ/yr
- Blast furnaces without scrubbers: 1.29 g TEQ/yr
- Reverberatory/co-located furnaces with scrubbers: 0.03 g TEQ/yr
- Reverberatory/co-located furnaces without scrubbers: 0.24 g TEQ/yr
- Rotary furnaces with scrubbers: 0.01 g TEQ/yr
- Rotary furnaces without scrubbers: 0.01 g TEQ/yr

A "medium" confidence rating is ascribed to the emission factors derived above because stack test data were available for 3 of the 23 active smelters in the United States and the stack test data used represent the three major furnace configurations. The "production" estimate has been assigned a "medium" confidence rating because, although it is based on a U.S. Department of Commerce estimate of total U.S. production, no production data were available on a furnace type or furnace configuration basis.

Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual emissions (1.6 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 0.7 to 3.5 g TEQ/yr.

3.6.8. Primary Ferrous Metal Smelting/Refining

Several European investigators have reported that iron ore sinter plants are sources of CDD/CDFs (Rappe et al., 1992b; Lexen et al., 1993; Lahl, 1993). However, insufficient information is available for evaluating CDD/CDF emissions from primary smelting/refining of ferrous metal in the United States.

Iron is manufactured from its ores (i.e., magnetic pyrites, magnetite, hematite, and carbonates of iron) in a blast furnace, and the iron obtained from this process is further refined in steel plants to make steel. During iron manufacturing, iron ores undergo

sintering to enable better processing in the blast furnace. In the sintering process, iron ore fines are mixed with coke fines and the mixture is placed on a grate which is then heated to a temperature of 1093-1371°C. The heat generated during combustion sinters the small particles. Also, iron-bearing dusts and slags from other processes in the steel plant are recycled as a feed mix for the sinter plant (Knepper, 1981; Capes, 1983). Lahl (1993) reported that the this management practice introduces traces of chlorine and organic compounds which are responsible for the generation of the CDD/CDFs found in these plants.

Sinter plants in Sweden and the Netherlands were reported to emit up to 3 ng TEQ/m^3 stack gas or 2 to 4 g TEQ/yr per plant to the air (Rappe et al., 1992b; Lexen et al., 1993). Lahl (1993) report that emission data from plants in Germany indicate TEQ concentrations in stack gas after passage through mechanical filters and electrostatic precipitators ranging from 3 to 10 ng TEQ/nm^3. Lahl (1993) estimated that, if all European sinter plants have stack concentrations of the same order of magnitude, then the total emission from sintering plants would be greater than 1 kg TEQ. This total is greater than the sum of all other identified European thermal sources of CDD/CDFs.

3.6.9. Secondary Ferrous Metal Smelting/Refining

Tysklind et al. (1989) found scrap ferrous metal processing to be a source of CDDs and CDFs at a steel mill in Sweden. Analyses showed the presence of CDDs and CDFs in the range of 0.1 to 1.5 ng TEQ/Nm^3 dry gas in a plant with a 10-ton electric furnace. The higher values reportedly were obtained during the melting of metal with chlorinated materials (e.g., PVC plastics). Raw gases collected over an open-furnace during batch jobs contained 110 ng TEQ/Nm^3 dry gas when cutting oils containing chlorine were added to the scrap metal. The congener profiles of all flue gas samples showed that CDFs were predominant. The congener profiles also showed higher chlorine content when PVC was used.

Insufficient data exist to estimate emission factors for the U.S.

3.6.10. Scrap Electric Wire Recovery

The objective of wire recovery is to remove the insulating material and reclaim the metal (e.g., copper, silver, and gold) comprising the electric wire. The reclaimed metal is then sold to a secondary metal smelter. Wire insulation commonly consists of a variety of plastics, asphalt-impregnated fabrics or burlap. In ground cables, chlorinated organics are used to preserve the cable casing.

In the past, scrap electric wire was thermally treated in the United States to burn off the insulating material. However, according to industry and trade association representatives, current recovery operations typically no longer involve thermal treatment but instead involve mechanical chopping into fine particles from which the insulating material is removed by air blowing and gravitational settling of the heavier metal fraction (telephone conversation between R. Garino, Institute of Scrap Recycling Industries, and T. Leighton, Versar, Inc. on March 2, 1993; telephone conversation between J. Sullivan, Triple F. Dynamics, and T. Leighton, Versar, Inc., on March 8, 1993). No independent confirmation of this technology switch could be obtained from EPA program office representatives.

The combustion of chlorinated organic compounds catalyzed by the presence of wire metals such as copper and iron can lead to the formation of CDDs and CDFs (Van Wijnen et al., 1992). CDDs and CDFs have been detected in fly ash and bottom residues from the open-air incineration of wire scraps, and in stack samples of a wire reclamation incinerator (Chen et al., 1986; Southerland et al., 1987). Huang et al. (1992b) detected CDDs and CDFs in soils collected near electronic wire scrap incinerators used for the recovery of metals. In these studies, the chlorinated compounds were considered to have been generated thermochemically from plastics covering the wires. Small-scale (and unpermitted) activities involving the incineration of scrap electrical wires have resulted in increased levels of CDDs and CDFs in soil samples collected from former scrap wire and car incineration sites within the vicinity of Amsterdam (Van Wijnen et al., 1992). Analysis of these soil samples showed CDD and CDF levels ranging between 60 and 98,000 ng/kg dry weight, with nine of fifteen soil samples having levels above 1,000 ng/kg dry weight.

Dioxin-like compounds emitted to the air from scrap electric wire incineration were measured from a facility during EPA's National Dioxin Study of combustion sources (U.S. EPA, 1987). The tested facility was determined to be typical of this industrial source category at that time. Insulated wire and other metal-bearing scrap material were fed to the incinerator on a steel pallet. The incinerator was operated in a batch mode, with the combustion cycles for each batch of scrap feed lasting between 1 and 3 hours. Incineration of the material occurred by burning natural gas. Most of the wire had a tar-based insulation that was thermally removed; however, PVC coated wire was also fed to the incinerator. The estimated temperature during combustion was 650°C, and combustion preceded in a primary and secondary chamber. The tested facility was equipped with a high temperature afterburner to further destroy organic compounds entrained in the combustion gases prior to discharge to the air from the stack. Emission factors estimated for this one facility include an average emission factor for TEQ of 1.18E-02 μg/kg of scrap wire (range = 6.74E-03 to 1.69E-02 μg/kg), and an average emission for total CDD/CDF of 9.89E-01 μg/kg of scrap wire (range = 9.89E-01 to 3.28E+00 μg/kg). These emission factors are assigned a "low" confidence rating because the factors were derived from measurements at only one facility operating in the U.S. and it is not known how representative these test results are of other scrap electric wire incinerators. Although it is uncertain how many facilities still combust scrap wire, for purposes of this assessment, it is assumed that only minimal quantities of scrap wire are currently burned in the United States.

3.6.11. Drum and Barrel Reclamation and Incineration

Hutzinger and Fiedler (1991b) reported that the CDDs and CDFs are emitted in stack gases from drum and barrel reclamation facilities and that the concentration of CDDs/Fs found in those emissions range from 5 to 27 ng/m^3. Dioxin-like compounds were measured by EPA in the stack gas emissions of a drum and barrel reclamation furnace as part of the National Dioxin Study (U.S. EPA, 1987). These plants operate a burning furnace to prepare used steel 55-gallon drums for cleaning to base metal. The drums processed at these facilities come from a variety of sources in the petroleum and chemical

industries. The cleaned drums are repaired, repainted, relined and sold for reuse. The drum burning process subjects used drums to an elevated temperature in a tunnel furnace for a sufficient time so that the paint, interior linings, and previous contents are burned or disintegrated. The furnace is fired by auxiliary fuel. Used drums are loaded onto a conveyor that moves at a fixed speed. As the drums pass through the preheat and ignition zone of the furnace, additional contents of the drums drain into the furnace ash trough. A drag conveyor moves these sludges and ashes to a collection pit. The drums are air cooled as they exit they furnace. Exhaust gases from the burning furnace are drawn through a breeching fan to a high-temperature afterburner.

Emission factors of dioxin-like compounds were developed from EPA stack tests of a prototypical operation (U.S. EPA, 1987) yielding the following emission factors in units of μg/kg: minimum TEQ = 1.12E-02; mean TEQ = 1.65E-02; maximum TEQ = 2.69E-02; mean CDD/CDF = 1.30E+00; minimum CDD/CDF = 1.16E+00; maximum CDD/CDF = 1.85E+00.

Approximately 2.8 to 6.4 million 55-gallon drums are incinerated annually in the United States (telephone conversation between P. Rankin, Association of Container Reconditioners, and C. D'Ruiz, Versar, Inc., December 21, 1992). This estimate is based on the following assumptions: 1) 23 to 26 incinerators are currently in operation; 2) each incinerator, on average, handles 500 to 1,000 drums per day; and 3) on average, each incinerator operates 5 days per week with 14 days downtime per year for maintenance activities. The weight of 55-gallon drums varies considerably; however, on average, a drum weighs 38 lbs (or 17 kg). Therefore, an estimated 48 to 109 million kg of drums are estimated to be incinerated annually. Assuming that 109 million kg of drums are burned each year and applying the mean emission factors developed above, the best estimates of annual emissions are 140 grams per year of total CDD/CDF and 1.7 grams per year of TEQ.

A "low" confidence rating is assigned to the production estimate since it is based an expert judgement rather than a published reference. A "low" confidence rating is ascribed to the emission factor since it is developed from stack tests conducted by EPA on just one U.S. drum and barrel furnace and this one facility may not represent emissions

from all current operations in the U.S. Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (1.7 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 0.5 to 5.4 g TEQ/yr.

3.6.12. Tire Combustion

Emissions of dioxin-like compounds from the incineration of automobile tires were measured from a tire incinerator stack tested by the State of California Air Resources Board (CARB, 1991). The facility consists of two excess air furnaces equipped with steam boilers to recovery the energy from the heat of combustion. Discarded whole tires are fed to the incineration units at a rate of 3000 kg/hr. The furnaces are equipped to burn natural gas as auxiliary fuel. The steam produced from the boilers is used to drive electrical turbine generators that produce 14.4 megawatts of electricity. The facility is equipped with a dry acid gas scrubber and fabric filter for the control of emissions prior to exiting the stack.

Emission factors for total CDD/CDF and TEQ in units of μg/kg of tires combusted were derived as average values from the one tested facility stack tested in California (CARB, 1991). From these data, an average emission factor of CDD/CDF was estimated to be 1.39E-02 μg/kg of tires incinerated (range: 4.28E-03 to 3.05E-02 μg/kg), and average emission factor of TEQ was estimated to be 5.42E-04 μg/kg (range: 1.91E-04 to 1.02E-03 μg/kg).

EPA's Office of Solid Waste estimates that approximately 0.50 million metric tons of tires are incinerated in the United States annually (U.S. EPA, 1992a). This production estimate is given a "high" confidence rating since it is based on detailed study specific to the United States. The use of scrap tires as a fuel increased significantly during the late 1980s. In 1990, 10.7 percent of the 242 million scrap tires generated were burned for fuel. This percentage is expected to continue to increase (U.S. EPA, 1992a).

If it is assumed that 500 million kilograms of discarded tires are incinerated annually in the United States, then, using the emission factors derived from stack data from the one

tested facility, an average of 6.9 grams of total CDD/CDF per year and an average of 0.3 grams of TEQ per year are estimated to be emitted to the air. It must be noted that these may be underestimates of emissions from this source category because the one facility tested in California is equipped with a dry-scrubber combined with a fabric filter for air pollution control. These devices are capable of greater than 95 percent reduction and control of dioxin-like compounds prior to discharge from the stack. It is not know to what extent other tire incineration facilities operating in the U.S. are similarly controlled. If such facilities are not so equipped, then the uncontrolled emission of CDD/CDF and TEQ could be much greater than the estimates developed above. Therefore, the estimated emission factor of dioxin from tire incineration is given a "low" confidence rating. Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (0.3 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 0.1 to 1.0 g TEQ/yr.

Buser et al. (1991) indicated that PCDTs (polychlorinated dibenzothiophenes, possibly a dioxin-like compound) can be formed in situations where large amounts of sulfur and chlorine-containing compounds are incinerated or accidentally burned. Automobile tires are known to contain sulfurous (vulcanization) compounds and certain types of chloro compounds (e.g., chloroprene). Thus, it is possible that the burning of used automobile tires could result in the formation of PCDTs.

3.6.13. Motor Vehicle Fuel Combustion

Some of the first evidence that CDD/CDFs might be created during the combustion processes in gasoline- and diesel-fueled engines came from Ballschmiter et al. (1986) who measured these compounds in used motor oil in Germany. Incomplete combustion and the presence of a chlorine source in the form of additives in the oil or the fuel (such as dichloroethane or pentachlorophenate) were speculated to lead to the formation of CDDs and CDFs. The isomeric patterns were characterized as typical of combustion processes.

Marklund et al. (1987) provided the first direct evidence of these compounds in car emissions based on tailpipe measurements on four Swedish cars running on leaded

gasoline. They found 20 to 220 pg of TEQ per kilometer driven. For this study, a nonleaded gasoline was used to which was added tetramethyl lead (0.15 grams of lead per liter or 0.57 grams per gallon) and dichloroethane (0.1 g/L as a scavenger). The fuel used may not accurately represent commercial fuels which typically contain a mixture of chlorinated and brominated scavengers (Marklund et al., 1990). Also, the lead content of the fuel used (0.15 g lead/L), although the normal lead content for Swedish fuels (Marklund et al., 1990), is higher than the lead content of leaded gasoline in the United States during the late 1980s (lowered to 0.10 g lead/gallon or 0.026 g lead/L effective January 1, 1986). For two cars running on unleaded gasoline, CDD/CDF emissions were below the detection limit which corresponded to approximately 13 pg of TEQ per kilometer driven. Table 3-33 presents a summary description of this study and subsequent studies discussed below.

Bingham et al. (1989) also analyzed 2,3,7,8-substituted CDD/CDFs in automobile exhausts. Four cars using leaded gasoline (0.45 g/L tetramethyllead, 0.22 g/L dichloroethane and 0.2 g/L dibromoethane) were tested and one car using lead free gasoline was tested. Only HpCDD and OCDD were detected in the exhaust from the vehicle using lead-free fuel. The total TEQ emission rate, based on these detected congeners, was 1 pg/km; the detection limit for the other 2,3,7,8-substituted CDD/CDFs was a combined 28 pg TEQ/km. 2,3,7,8-TCDF was detected in the exhaust of two of four cars using leaded fuel. OCDD was detected in the exhaust from three of the cars and PeCDF and HpCDD were each detected in the exhaust from one car. TEQ emission rates for the cars using leaded fuel, based on detected congeners, was 5 to 39 pg/km.

Haglund et al. (1988) sampled exhaust gases from three different vehicles (two cars fueled with leaded and unleaded gasoline, respectively, and a heavy diesel truck) for the presence of brominated dibenzo-p-dioxins (BDD) and brominated dibenzofurans (BDF). The authors concluded that the dibromoethane scavenger added to the tested gasoline probably acted as a halogen source. TBDF emissions measured 23 ng/km in the car with leaded gasoline and 0.24 ng/km in the car with unleaded gasoline. TBDD and PeBDF emissions measured 3.2 and 0.98 ng/km, respectively in the car with leaded gasoline. All BDD/Fs were below detection limits in the diesel truck emissions.

Table 3-33. Descriptions and Results of Vehicle Emission Testing Studies for CDDs and CDFs

Study	Country	Fuel Type	Scavenger[a]	Catalyst Equipped	Number of Test Vehicles	Emission Factor (pg TEQ/km driven)	Driving Cycle; Sampling Location
Marklund et al. (1987)	Sweden	Unleaded Leaded	No Yes	Yes No	2 4	<13 20-220	A10 (2 cycles); muffler exhaust A10 (2 cycles); muffler exhaust
Bingham et al. (1989)	New Zealand	Unleaded Leaded	No Yes	NR NR	1 4	1 5-39	A10 (3 or 4 cycles); muffler exhaust A10 (3 or 4 cycles); muffler exhaust
Marklund et al. (1990)	Sweden	Unleaded Leaded Unleaded Leaded Diesel	No Yes No Yes None	No No Yes No NR	2 2 1 2 1	0.36-0.39 2.6-6.3 0.36 1.1-2.6 not detected	FTP-73 test cycle; before muffler FTP-73 test cycle; before muffler FTP-73 test cycle; in tailpipe FTP-73 test cycle; in tailpipe U.S. Federal mode 13 cycle; before muffler
Hagenmaier et al. (1990)	Germany	Unleaded Unleaded Leaded Diesel	No No Yes No	No Yes No NR	1 1 1 1	5.1[b] 0.7[b] 108[b] 50[b]	Comparable to FTP-73 test cycle; in tailpipe Comparable to FTP-73 test cycle; in tailpipe Comparable to FTP-73 test cycle; in tailpipe Comparable to FTP-73 test cycle; in tailpipe
Oehme et al. (1991) (tunnel study)	Norway	---	---	---	(c)	520[d] 38[d] avg = 280 9,500[d] 720[d] avg = 5,100	Cars moving uphill (3.5% incline) at 60 km/hr Cars moving downhill (3.5% decline) at 70 km/hr Trucks moving uphill (3.5% incline) at 60 km/hr Trucks moving downhill (3.5% decline) at 70 km/hr

[a] Dichloroethane and dibromoethane, except for Marklund et al. (1987), used as scavengers.

[b] Results reported by Hagenmaier et al. (1990) were in units of pg TEQ/liter of fuel. For purposes of this table, the fuel economy factor used by Marklund et al. (1990), 10 km/L or 24 miles/gal, was used to convert the emission rates into units of pg TEQ/km driven for the gasoline-fueled vehicle. For the diesel-fueled truck, a factor of 2 km/L (or 5 miles/gal) was used.

[c] Tests were conducted over portions of 4 days with traffic rates of 8,000-14,000 vehicles/day. Heavy duty vehicles ranged from 4-15% of total.

[d] Emission factors are reported in units of pg Nordic TEQ/km driven.

More recently, Marklund et al. (1990) tested gasoline- and diesel-fueled vehicles, measuring CDD/CDF emissions before and/or after the muffler of Swedish vehicles (including new and old vehicles). Marklund et al. (1990) reported the emission results in units of pg TEQ/L of fuel consumed and also in units of pg TEQ/km driven during the test. Based on the test driving cycle employed (i.e., 31.7 km/hr as a mean speed; 91.2 km/hr as a maximum speed; and 17.9 percent of time spent idling), Marklund et al. (1990) observed a fuel economy of approximately 9 to 10 km/L or 22 to 24 miles/gallon. The following measurements were reported:

- leaded gas/cars/before muffler: 2.4 to 6.3 pg TEQ/km (or 21 to 60 pg TEQ/L of fuel consumed)
- leaded gas/cars/in tailpipe: 1.1 to 2.6 pg TEQ/km (or 10 to 23 pg TEQ/L).
- lead-free gas/catalyst-equipped car/in tailpipe: 0.36 pg TEQ/km (or 3.5 pg TEQ/L)
- lead-free gas/cars/before muffler: 0.36 to 0.39 pg TEQ/km (or 3.5 pg TEQ/L)
- diesel fuel/heavy-duty truck/before muffler: not detected (i.e., less than 100 pg TEQ/L)

Regarding the diesel fuel measurement, the authors pointed out that the test fuel was a reference fuel and may not be representative of commercial diesel fuel. Also, due to analytical problems, a much higher detection limit (about 100 pg TEQ/L) was employed in the diesel fuel tests than in the gasoline tests (5 pg TEQ/L). Further uncertainty is introduced by the fact that diesel emission samples were only collected prior to the muffler. The TEQ levels in exhaust gases from older cars using leaded gasoline were up to six times greater when measured before the muffler than after the muffler. No muffler-related difference in new cars running on leaded gasoline or in old or new cars running on unleaded gasoline were observed.

Hagenmaier et al. (1990) ran a series of tests on gasoline engines for light duty vehicles in Germany. The following average TEQ emission rates per liter of fuel consumed were found:

- Leaded fuel: 1.083 ng TEQ/L
- Unleaded fuel (catalyst-equipped): 0.007 ng TEQ/L
- Unleaded fuel (not catalyst-equipped): 0.051 ng TEQ/L
- Diesel fuel: 0.024 ng TEQ/l

Several European studies have evaluated CDD/CDF emissions from vehicles by measuring the presence of CDD/CDFs in tunnel air. This approach has the advantage that it allows random sampling of large numbers of cars, including a range of ages and maintenance levels. The disadvantage of this approach is that it relies on indirect measurements (rather than tailpipe measurements) which may introduce unknown uncertainties and make interpretation of the findings difficult. Concerns have been raised that the tunnel monitors are detecting resuspended particulates which have accumulated over time, leading to overestimates of emissions. Also, the driving patterns encountered in these tunnel studies are more or less steady state driving conditions rather than the transient driving cycle and cold engine starts that are typical of urban driving conditions and which may affect emission levels. Wevers et al. (1992) found that CDD/CDF levels inside a Belgium tunnel were about twice the levels in ambient air and estimated the average level in vehicle emissions as 42 to 45 pg TEQ/Nm^3. Rappe et al. (1988) conducted a similar tunnel study in Sweden and Oehme et al. (1991) conducted a similar study at a tunnel in Norway, the preliminary results of which were reported by Larssen et al. (1990). The Oehme et al. (1991) study estimated emissions for light duty and heavy duty vehicle classes. This was completed by counting the number of light duty vs. heavy duty vehicles passing through the tunnel during the study. The mean emission rate estimates from this study are:

- Light-duty vehicles using gasoline (approximately 30 percent using leaded gas): 0.28 ng TEQ/km
- Heavy-duty diesel trucks: 5.1 ng TEQ/km

These mean values are the averages of the emission rates corresponding to two operating modes: vehicles moving uphill on a 3.5 percent incline and vehicles moving downhill on a 3.5 percent decline. The TEQ emission rates for the two modes differ by an order of magnitude for both light and heavy duty vehicles. Although Oehme et al. (1991) reported results in units of Nordic TEQs rather than I-TEQs, the results in I-TEQ should be virtually identical because the only difference between the two TEQ schemes is the factor assigned to 1,2,3,7,8-PeCDF (0.1 in Nordic and 0.05 in I-TEQ), a minor component of the toxic CDD/CDFs measured in the tunnel air.

Virtually no testing of vehicle emissions in the United States for CDD/CDFs has been published. In 1987, the California Air Resources Board (CARB) produced a draft report on the testing of the exhausts of four gasoline-powered cars and three diesel fuel-powered vehicles (one truck, one bus, and one car) (CARB, 1987). However, CARB has indicated to EPA that the draft report should not be cited or quoted to support general conclusions about CDD/CDFs in motor vehicle exhausts because of the small sample size of the study and because the use of low rather than high resolution mass spectrometry in the study resulted in high detection limits and inadequate selectivity in the presence of interferences (Lew, 1993). CARB did state that the results of a single sample from the heavy-duty diesel truck could be reported because congeners from most of the homologue groups were present in the sample at levels that could be detected by the analytical method and there were no identified interferences in this sample. However, it should be noted that this test was conducted under steady state conditions and at low speeds which are not indicative of normal driving patterns. The TEQ content of this one sample was 218 pg per dry standard cubic meter (dscm) of exhaust. The CARB results suggest that diesel-fueled trucks do emit CDD/CDFs (Lew, 1993).

Jones (1993) estimated CDD/CDF emissions of the major vehicle types on the basis of the studies by Larssen et al. (1990), the 1987 draft report by CARB, and Hagenmaier et

al. (1990). Using data on vehicle miles travelled in the U.S. and an assumed emission rate of 5.4 ng TEQ/km based on Larssen et al. (1990), Jones (1993) estimated that about 1000 g of TEQ were emitted from diesel vehicles nationwide in 1990. Jones (1993) also suggests that human exposure to diesel emissions are exacerbated relative to stack emissions from combustion sources on the basis that diesel emissions occur at ground level and that, unlike stack emissions, may not undergo much dilution in air before human contact occurs.

In 1973, EPA required refiners to meet a 0.5 gpg (gram per gallon) standard for the average lead content of all gasoline. EPA later replaced this standard with a standard for the lead content of leaded gasoline only. Effective November 1, 1982, large refineries were required to meet a standard of 1.10 grams per leaded gallon (gplg). Certain smaller refineries were subject to a 1.90 gplg standard until July 1, 1983, at which time they would also be subject to the 1.10 gplg standard (Federal Register, 1982). EPA further reduced the standard to 0.10 gplg effective January 1, 1986 with a[n] interim standard of 0.5 gplg effective July 1, 1985 (Federal Register, 1985). The Clean Air Act Amendments of 1990 imposed further restrictions as follows: "After December 31, 1995, it shall be unlawful for any person to sell, offer for sale, supply, offer for supply, dispense, transport, or introduce in commerce, for use as fuel in any motor vehicle any gasoline which contains lead or lead additives."

In 1985, the year before the phasedown of leaded gasoline from 1.10 gplg to 0.10 gplg, approximately 1,774 billion miles (2,855 billion km) were driven (U.S. DOC, 1992). Because leaded gasoline accounted for 35.5 percent of the gasoline supply that year (EIA, 1993) it can be estimated that 1,013 billion of these kilometers (i.e., 35.5 percent of 2,855 billion km) were driven by vehicles powered with leaded gasoline.

The U.S. Federal Highway Administration, as reported in U.S. DOC (1992), reports that 2,148 billion total vehicle miles (3,456 billion km) were driven in the U.S. during 1990. During 1990, automobiles and motorcycles accounted for 1,525 billion vehicle miles (2,454 billion km). Trucks accounted for 617 billion vehicle miles (993 billion km) and buses accounted for 5.7 billion vehicle miles (9.2 billion km) (U.S. DOC, 1992). In 1987, diesel-fueled trucks accounted for 17.2 percent of total truck vehicle km driven;

gasoline-fueled trucks accounted for the remaining 82.8 percent (U.S. DOC, 1990b). Applying this factor (i.e., 17.2 percent) to the 1990 km truck mile estimate (i.e., 993 billion km) indicates that an estimated 171 billion km were driven by diesel-fueled trucks in 1990. It is assumed that all other vehicle km driven (3,285 billion km) were those of gasoline-powered vehicles. In 1990, leaded gasoline accounted for only 5.3 percent of total gasoline supplies (EIA, 1993). These mileage estimates are given a "high" confidence rating on the basis that they are based on U.S. Census of Transportation studies.

Using the above literature, separate emission estimates were developed for vehicles burning leaded gasoline, unleaded gasoline and diesel fuel:

- ***Leaded Gasoline:*** In general, the literature indicates that CDD/CDF emissions occur from vehicles using leaded gasoline and that considerable variation occurs depending, at least in part, on the types of scavengers used. Marklund et al. (1987) reported emissions ranging from 20 to 220 pg TEQ/km from four cars fueled with a reference fuel (0.5 gplg) to which lead and a chlorinated scavenger were added. Marklund et al. (1990) reported much lower emissions in the tailpipe exhaust of two cars (1.1 to 2.6 pg TEQ/km) using a commercial leaded fuel (0.57 gplg). Marklund et al. (1990) attribute the difference in the emission measurements to the different scavengers used in the two studies. Hagenmaier et al. (1990) reported TEQ emissions of 1,083 pg/L of fuel (or approximately 108 pg TEQ/km) from a car fueled with a commercial leaded fuel (lead content not reported). Bingham et al. (1989) reported emissions from four cars using gasoline with a lead content of 1.7 gplg in New Zealand to range from 5 to 39 pg/km. The tunnel study by Oehme et al. (1991) indicated that emissions from cars could be 38 to 520 pg TEQ/km. Since most of the vehicles passing through the tunnel studied by Oehme et al. (1991) used unleaded fuels (approximately 70 percent), the emissions from leaded fuel-powered cars were possibly even higher.

On the basis of the three studies performed using commercial leaded fuel, an emission factor range of 1.1 to 108 pg TEQ/km is recommended. A "low" confidence rating is assigned to this factor range because the range is based on European fuels and

emission control technologies which may differ from U.S. fuels and technology and also because the factor range is based is based on tests with only seven cars. Combining this emission factor range with the estimates for km driven by leaded fuel-powered vehicles in 1985 (1,013 billion km or 35.5 percent of total km) and in 1990 (174 billion km or 5.3 percent of the 3,285 billion km driven by gasoline-powered vehicles) suggests that about 1.1 to 109 g TEQ/yr were emitted from vehicles using leaded fuels in 1985, the year immediately before the phasedown of leaded gasoline from 1.10 gplg to 0.10 gplg and the year when the interim standard of 0.5 gplg became effective. By comparison, the annual emission for 1990 from use of leaded gasoline is estimated to have ranged from 0.2 to 19 g TEQ.

- ***Unleaded Gasoline:*** The literature clearly indicates that CDD/CDF emissions are much less from vehicles burning unleaded fuels. The Marklund et al. (1990) study is the only one which provided an emission factor for this class of vehicles. On the basis of this study, an emission factor of 0.36 pg TEQ/km is recommended. A "low" confidence rating is assigned to this factor because the Swedish fuels and emission control technology used in the Marklund et al. (1990) study may differ from U.S. fuels and technology and also because the emission factor is based on tests with only one catalyst-equipped car. Combining this emission factor with the above estimates for vehicle km driven in 1990 by gasoline-powered vehicles (3,285 billion), suggests that about 1.3 g of TEQ/yr were emitted from vehicles using unleaded fuels in 1990. Based on the low confidence rating, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (1.3 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 0.4 to 4.1 g TEQ/yr.

- ***Diesel Fuel:*** Very few data are available upon which to base an evaluation of the extent of dioxin emissions resulting from diesel fuel combustion. The tunnel study by Oehme et al. (1991) generated an estimated emission factor of 5.1 ng TEQ/km. A "low" confidence rating is assigned to this factor because the factor is based on Norwegian fuels and

emission control technology which may differ from U.S. fuels and technology. Also, although aggregate samples were collected representing hundreds of vehicles, the indirect method of analysis and the more or less steady state rather than transient driving conditions of the study introduce considerable uncertainty.

The results of only one tailpipe measurement (diesel fuel in a heavy-duty Swedish truck) have been published (Marklund et al., 1990) and that study reported no emissions at a detection limit of 100 pg TEQ/L. If it is assumed that the fuel economy of heavy-duty diesel vehicles is approximately 5 miles/gallon (or 2 km/L), then 100 pg TEQ/L converts to approximately 0.05 ng TEQ/km - a factor 100-fold lower than the emission rate reported by Oehme et al. (1991). Because the results of Marklund et al. (1990) are based on only one vehicle using a Swedish reference, not a commercial, diesel fuel this emission factor is also assigned a "low" confidence rating.

To obtain an estimate of the possible range of dioxin TEQ annual emissions resulting from diesel fuel use, the geometric mean of the emission factors derived from the Oehne et al. (1991) and Marklund et al. (1990) was calculated (0.5 ng TEQ/km). Combining this emission factor with the above estimate for vehicle kms driven in 1990 in the United States by diesel-fueled trucks (171 billion km) yields an annual emission estimate of 85 g TEQ/yr. Based on the low confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (85 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 27 to 270 g TEQ/yr.

3.6.14. Wood Burning at Residences

Measurable levels of TCDDs have been found in chimney soot and bottom ash from wood-burning stoves and fireplaces (Clement et al., 1985b; Wenning et al., 1992). Chimney deposits from residential wood burning have been found to have CDD/CDF congener profiles similar to those in flue gases from municipal waste incineration (Bacher et al., 1992). Bacher et al. (1992) found concentrations of 2,3,7,8-substituted CDF and CDD congeners in soot from wood burning ranging from 40 to 930 ng/kg and from 30 to 150 ng/kg, respectively. Bacher et al. (1992) reported that the CDFs dominated the CDDs

by a factor of 5 to 10 and that the lower chlorinated CDDs/CDFs (mono-through tri-) dominated the more chlorinated CDDs/CDFs. The TEQ content of the chimney soot was 720 ng/kg (Bacher et al., 1992).

Nestrick and Lamparski (1983) conducted a study of CDD formation in residential wood-burning chimneys in different areas of the United States. The results of their survey are presented in Table 3-34. As seen in Table 3-28, the eastern U.S. had overall higher estimated levels of TCDD generation than did the central or western United States. Levels of TCDDs in chimney soot ranged from 22 to 410 ng/kg for the eastern U.S., 21 to 294 ng/kg in the central U.S., and 2.9 to 28 ng/kg in the western U.S. Red oak and oak were the predominant fuels used in the eastern and western U.S., and ash, birch, and oak were the predominant fuels used in the central U.S.

Two studies have recently become available which provide direct measurement of CDD/CDF in emissions from wood stoves. These studies are summarized below.

Schatowitz et al. (1993) measured CDD/CDF in the emissions of a variety of residential wood burners in Switzerland. The study included three types of burners (household stoves, automatic chip burners, and wood boilers) and a variety of wood fuels (natural beech wood, natural wood chips, chipboard chips, waste wood chips, charcoal and household waste). The following emission factors were derived:

- household stove with open door burning natural beech wood: 0.77 ng TEQ/kg
- household stove with closed door burning natural beech wood: 1.25 ng TEQ/kg

The open door stove can be assumed to be representative of fireplaces since both have an uncontrolled draft. Also, Schatowitz et al. (1993) measured emissions from wood burning fireplaces and report the same flue gas concentration as found with the open door wood stove (i.e., 0.064 ng TEQ/m^3). All of the toxic congeners of CDD/CDF were found at levels above the detection limit.

Vikelsoe et al. (1993) studied emissions of CDD/CDFs from residential wood stoves in Denmark. The wood fuels used in the experiments were seasoned birch, beech and spruce harvested in Denmark. Four different types of stoves were evaluated under normal

Table 3-34. Average Concentrations (ppt) of TCDDs in Chimney Soot from Residential Wood-Burning Stoves in the U.S.

TCDD Isomer	Eastern U.S.[a]	% of Total TCDDs	Central U.S.[b]	% of Total TCDDs	Western U.S.[c]	% of Total TCDDs
2,3,7,8	132	3	110	4	13	4
1,4,6,9	22	1	21	1	2.9	1
1,2,6,9	115	3	80	3	8.3	3
1,2,6,7	82	2	42	2	4.1	1
1,2,8,9	93	2	49	2	5.4	2
1,3,6,9	155	4	150	6	17	5
1,2,4,7/1,2,4,8	367	9	254	10	26	8
1,2,7,8	225	6	168	7	17	5
1,2,6,8	245	6	194	8	19	6
1,2,3,7/1,2,3,8	410	10	294	12	28	9
1,2,7,9	233	6	219	9	27	9
1,2,4,6	130	3	60	2	7.7	2
1,4,7,8	67	2	77	3	11	4
1,2,3,6	141	4	56	2	7.5	2
1,2,3,9	143	4	64	3	8.1	3
1,2,4,9	128	3	83	3	12	4
1,3,6,8	352	9	181	7	17	5
1,3,7,9	403	10	166	7	14	4
1,3,7,8	343	9	212	8	23	7
1,2,3,4	162	4	36	1	3.4	1
Total TCDDs	3948		2517		314	

Source: Nestrick and Lamparski (1983)

[a] Ash samples from 3 masonry chimneys in which red oak was the predominant fuel.
[b] Ash samples from 3 masonry chimneys in which ash, birch, or oak were the predominant fuel.
[c] Ash samples from one chimney and five metal chimneys in which oak was the predominant fuel.

and optimal operating conditions. Widely varying emissions were found for different fuel/stove combinations. The emissions from spruce were about twice as high as the emissions from birch and beech. In many of the experiments the CDD/CDF emissions were higher when the stove was operated under normal conditions vs optimal conditions (minimum CO). The weighted average (considering wood and stove types) emission factor for wood stoves in Denmark was estimated to be 1.9 ng Nordic-TEQ/kg.

Based on the above studies, 1 ng TEQ/kg appears to be a reasonable average emission factor for residential wood burning. A "medium" confidence rating was assigned to this estimate on the basis that: (1) it is derived from only two studies; (2) both studies used direct measurement; and (3) although the studies were conducted in Europe, residential wood burning practices are probably sufficiently similar to apply to the United States.

In 1990, wood provided about 2.8 percent of the total primary energy consumed in the United States (EIA, 1991). Total wood energy consumption during 1990 is estimated at 2,359 trillion BTU. Assuming that 1 kg of oven-dried wood (i.e., 2.15 kg of green wood) provides approximately 19,000 BTU, then an estimated 124.2 million metric tons of oven-dried wood equivalents were burned for energy purposes in 1990 (EIA, 1991). Residential wood consumption in 1990 was estimated at 786 trillion BTU (41.4 million metric tons), or 33 percent of total U.S. consumption. Industrial fuel wood consumption in 1990 totaled 1,562 trillion BTU (82.2 million metric tons), or 66 percent of total U.S. consumption, with the majority (1,232 trillion BTU) of this fuel wood being consumed by the Paper and Allied Products Industry. 1990 consumption of fuel wood by the utility sector was approximately 11.9 trillion BTU (0.6 million metric tons) (EIA, 1991). These production estimates are given a "high" confidence rating since they are based on a detailed published study specific to the United States.

Combining the best estimate of the emission factor (1 ng TEQ/kg wood) with the mass of wood consumed annually by residences, indicates that the annual TEQ emissions from this source are about 40 grams. Based on the "medium" confidence rating assigned to the emission factor, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best

estimate of annual emissions (40 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 13 to 63 g TEQ/yr.

3.6.15. Industrial Wood-Burning Facilities

Emissions of dioxin-like compounds have been measured in stack emissions from an industrial wood-burning furnace by EPA (U.S. EPA, 1987). The tested facility was located at a lumber products plant that manufactures overlay panels and other lumber wood products. The wood-fired boiler tested was a three-cell dutch oven equipped with a waste heat boiler. During normal operation, the furnace is 100 percent fired with scrap wood from the lumber plant. The feed wood is a mixture of bark, hogged wood, and green and dry planar shavings. The composition of the feed was estimated to be wood from fir and hemlock. Nearly all the wood fed to the lumber plant had been stored in sea water adjacent to the facility, and therefore had a significant concentration of inorganic chloride. The scrap wood fed to the boiler had not been treated with chemical preservatives, e.g., pentachlorophenol. The wood was fed to the boiler by a screw conveyor that dumps the feed into a pile in the primary combustion chamber. The furnace is operated at air in 50 percent excess of stoichiometric requirements. Boilers capture the heat of combustion and transfer the heat into steam for co-generation of energy at the plant. The exhausted gases from the boiler pass through a cyclone and fabric filter prior to discharge from the stack. From this study, an average emission factor for CDD/CDF of 1.02 μg/kg of wood burned (range: 5.52E-01 to 1.41E+00 μg/kg), and an average emission factor for TEQ of 1.71E-02 μg/kg of wood burned (range: 7.34E-03 to 2.28E-02 μg/kg) are estimated. Emissions testing at this facility demonstrated that the fabric filter was reducing dioxin emissions by about 90 percent (U.S. EPA, 1987).

In a second study, CDD/CDF was measured in the emissions from a quad-cell wood-fired boiler used to generate electricity (CARB, 1990b). The fuel consisted of coarse wood waste and sawdust from nonindustrial logging operations. The exhaust gas passed through a multicyclone before entering the stack. This study suggests an emission factor of 5.4E-02 μg/kg for CDD/CDF. If the same TEQ to total CDD/CDF ratio is assumed as in

the first industrial burner study, then an emission factor of 9E-04 μg TEQ/kg can be estimated.

To obtain an estimate of the possible range of dioxin TEQ annual emissions resulting from industrial wood-burning facilities, the geometric mean of the emission factors derived from the U.S. EPA (1987) and CARB (1990b) studies was calculated (3.9 ng TEQ/kg wood). Because test data are available for only two facilities and because the emission factors measured at these two facilities vary greatly, this emission factor was given a "low" confidence rating.

In 1990, it was estimated that 82.2 million metric tons of wood were burned in industrial furnaces ("high" confidence rating, see discussion in Section 3.6.14). Applying the above emission factor to the estimated annual mass of wood burned by industrial facilities gives an estimated TEQ emission of 320 g TEQ/yr. Based on the low confidence rating given to the emission factor, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (320 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 100 to 1,000 g TEQ/yr.

3.6.16. Wood Burned in Forest Fires

Based on the findings of Wenning et al. (1992), Bacher et al. (1992), and Nestrick and Lamparski (1983), indicating generation of CDDs/CDFs in ash and soot during residential wood burning, it is reasonable to hypothesize that wood burned in forest fires may also be a source of CDDs/CDFs. Support for this hypothesis is provided by Bumb et al. (1980) who, in their study on trace chemistry of fire, have shown that combustion of hydrocarbons in the presence of chlorine compounds (which are naturally found at low levels in wood) can generate CDDs and CDFs in small amounts. Also, the pre-industrial existence of CDDs and CDFs, presumably due to combustion sources, has been demonstrated in analyses of ancient human tissues and ancient aquatic sediment deposits (ECETOC, 1992).

Only one study could be found that made direct measurements of CDD/CDFs in the actual emissions from forest fires. This study by Tashiro et al. (1990) detected levels

ranging from about 15 to 400 pg/m^3 for total CDD/CDFs. The samples were collected from fixed collectors 10 m above the ground and from aircraft flying through the smoke. Background samples collected before and after the tests indicated negligible levels in the atmosphere. These results were presented in the form of a preliminary report and no firm conclusions were drawn about whether forest fires are a CDD/CDF source. Coauthor Dr. Ray Clement presented the final report on this study at Dioxin '91. Clement and Tashiro (1991) reported total CDD/CDF levels in the smoke of about 20 pg/m^3. The authors concluded that CDD/CDFs are emitted during forest fires but recognized that some portion of these emissions could represent resuspension from residues deposited on leaves rather than newly formed CDD/CDFs.

The concentrations presented by Clement and Tashiro (1991) cannot accurately be converted to an emission factor since the corresponding rates of combustion gas production and wood consumption are not known. As a result, three alternative approaches were considered to develop these emission factors:

Soot-Based Approach: This approach assumes that the level of CDD/CDFs in chimney soot are representative of the CDD/CDFs in emissions, and estimates the CDD/CDF emission rate as the product of the soot level and the total particulate emission rate. This involves first assuming that the CDD/CDF levels measured by Bacher et al. (1992) in chimney soot (720 ng TEQ/kg) are representative of the CDD/CDF concentrations of particles emitted during forest fires. Second, the total particulate generation rate must be estimated. Ward et al.(1976) estimated the national average particulate emission factor for wildfires as 150 lb/ton biomass dry weight based primarily on data for head fires. Ward et al. (1993) estimated the national average particulate emission factor for prescribed burning as 50 lb/ton biomass dry weight. Combining the total particulate generation rates with the CDD/CDF levels in soot yields emission factor estimates of 54 μg of TEQ and 18 μg of TEQ/metric ton of biomass burned in wildfires and prescribed burning, respectively. This corresponds to a range of 54 to 18 ng TEQ/kg of biomass. This estimate is likely to be an overestimate since the levels of CDD/CDF measured in chimney soot by Bacher et al. (1992) may represent accumulation/enrichment

of CDD/CDFs measured in chimney soot over time, leading to much higher levels than what is actually on emitted particles.

Carbon Monoxide (CO) Approach: CO is a general indicator of the efficiency of combustion and the emission rate of many emission products can be correlated to the CO emission rate. The Schatowitz et al. (1993) data for emissions during natural wood burning in open stoves suggests an emission rate of 10 ug TEQ/kg of CO. Combining this factor with the CO production rate during forest fires (roughly 0.1 kg CO/kg of biomass - Ward et al. (1993)) yields an emission factor of 1000 ng TEQ/kg biomass. This factor appears unreasonably high since it is even higher than the soot-based factor discussed above. Although the formation kinetics of CDD/CDF during combustion are not well understood, it appears that CDD/CDF emissions do not correlate well with CO emissions.

Wood Stove Approach: This approach assumes that the emission factor for residential wood burning (using natural wood and open door, i.e., uncontrolled draft) applies to forest fires. As discussed in Section 3.6.14, this approach suggests an emission factor of about 1 ng TEQ/kg. This value appears more reasonable than the factors suggested by the soot and CO approaches. However, forest fire conditions differ significantly from combustion conditions in wood stoves. For example, forest fire combustion does not occur in an enclosed chamber and the biomass consumed in forest fires is usually green and includes underbrush, leaves and grass. Given these differences and the uncertainties about the formation kinetics of CDD/CDF during combustion, it is difficult to determine whether CDD/CDF emissions would be higher or lower from forest fires than from wood stoves. Thus, although an emission factor of 1 ng TEQ/kg appears to be the best estimate that can be made currently, it must be considered highly uncertain and a "low" confidence rating was assigned to this estimate.

According to the Council on Environmental Quality's 21st Annual Report (CEQ, 1990), an average of 5.1 million acres of biomass have been burned in wildfires every year from 1950 to 1990. This value also corresponds well to the data provided by the USDA

Forest Service for 1975 in which 4.4 million acres of biomass were burned in wildfires (Ward et al., 1976). Yearly estimates cited in the CEQ report (CEQ, 1990) ranged from a high of 15.5 million acres burned to an annual low of 1.8 million acres burned over the forty year time period. Additionally, 5.1 million acres of biomass were burned in 1989 during prescribed burns (Ward et al., 1993). Prescribed burning is also known as managed or controlled burning and is used as a forest management tool under exacting weather and fuel conditions. These acreage estimates can be combined with biomass consumption rates of 10.4 tons/acre in areas consumed by wildfires (Ward et al., 1976) and 8.2 tons/acre in areas consumed in prescribed burns (Ward et al., 1993). This combination suggests a total of 53 million tons (or 48 million metric tons) of biomass are consumed annually in wildfires while a total of 42 million tons (or 38 million metric tons) of biomass are consumed annually in prescribed burns. These production estimates were assigned a "medium" confidence rating since they are based on a combination of estimates involving detailed historical data specific to the United States on acres burned but less accurate estimates of biomass burned/acre.

Combining the emission factor developed using the "wood stove" approach (i.e., 1 ng TEQ/kg biomass) with the amount of biomass consumed annually in wildfires and prescribed fires (total of 86 million metric tons) indicates that the best estimate of annual TEQ emissions from this source is 86 g. Based on the low confidence rating given to the emission factor, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (86 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 27 to 270 g TEQ/yr.

Whether releases from this source result in significant human exposure is questionable. If wood burning today is a major source of human exposure to CDD/CDFs, then the tissues of ancient humans (who relied on wood as a fuel source more so than do humans in industrialized settings today) should have CDD/CDF levels that are a substantial fraction of the levels found in humans today. The 1987 NHATS study indicates that the U.S. average CDD/CDF adipose tissue concentration is currently about 1000 ppt (U.S. EPA 1990d) and Schecter (1991) reports that the total CDD/CDF concentration in liver tissues

today is about 400 ppt. However, with the exception of OCDD in one sample, Ligon et al. (1989) could not detect CDD/CDFs that exceeded the analytical background (detection limit = 0.3 to 5 ppt) in the mummified muscle tissues of nine 2,800 year old Chilean Indians. Similarly, Schecter (1991) examined the livers of two frozen 400 year old Eskimo women and found only HpCDD, OCDD, and HpCDF at levels only 15 percent of current levels.

3.6.17. Coal Combustion

Fiedler and Hutzinger (1992) estimate that 1.1 g of dioxin TEQ may be released to the atmosphere in Germany annually from residential combustion of coal. In the United Kingdom, combustion of coal by residential, industrial, and utility sources is estimated to account for 38 percent (1,489 g TEQ/yr) of all dioxin TEQ releases to the atmosphere (ECETOC, 1992). The Clean Air Act requires an assessment of the emissions of toxic air contaminants (including CDDs and CDFs) discharged from the stacks of coal-fired power plants. The EPA is collaborating with the U.S. Department of Energy to conduct this study. Stack testing at seven plants is currently underway and the results will be incorporated to the extent possible in the final version of this report.

In the United States, the consumption of coal accounts for approximately 25 percent of the energy consumed from all sources (U.S. DOC, 1992). In 1991, 806 million metric tons of coal were consumed in the United States (EIA, 1993). Of this total, 87 percent (or 701 million metric tons) was consumed by electric utilities, 12.3 percent (or 99 million metric tons) was consumed by the industrial sector, and 0.7 percent (or 5.5 million metric tons) was consumed by residential and commercial sources (EIA, 1993). These production estimates are assigned a "high" confidence rating since they are based on detailed studies specific to the U.S.

Derivation of emission factors is difficult due to the extremely limited data on emission of dioxin-like compounds from coal-fired utility boilers (NATO,1988). Most investigations of emissions from facilities in the United States have not reported the detection of dioxin congeners at the exit to the stack (NATO, 1988). Therefore in the development of emission factors representative of coal-fired utility boilers (coal-fired power

plants), the reported limit of detection of the analytical method was applied as an upper-bound to the plausibility of emissions of dioxin from the source. If it is assumed that burning one kg of coal in a modern power plant produces an estimated 6.2 dry standard cubic meters (dscm) of combustion gas, then the limit of detection from the study of U.S. power plants can be used to estimate an emission factor (NATO,1988). From the reported limit of detection of dioxin at the stack, an upper-bound emission factor for total CDD/CDF of 3.11E-02 μg/kg of coal combusted and an upper-bound emission factor for TEQ of 4.22E-04 μg/kg of coal combusted can be derived. If it is assumed that 700 billion kg of coal is combusted each year by power plants in the United States, then the upper-bound emission factors indicate an annual emission to the air of less than 2.2E+04 grams of total CDD/CDF and less than 3.0E+02 grams of TEQ/yr. The emission factors are assigned a "low" confidence rating because the stack emission of dioxin-like compounds from coal-fired utility boilers operating in the United States has yet to be determined. Emissions tests reported to date have not detected these compounds. The estimated emissions must, therefore, be considered the upper-bound of possible emissions from the source category based on available data.

3.6.18. Combustion of Polychlorinated Biphenyls (PCBs)

The accidental or intentional combustion of PCBs in incinerators and boilers not approved for PCB burning (40 CFR 761) may produce CDDs and CDFs. At elevated temperature, such as those in transformer fires, PCBs can undergo reactions to form CDF and other by-products. Several accidental fires in the U.S. and Sweden which involved the combustion of PCBs and the generation of CDDs and CDFs are discussed in Hutzinger and Fiedler (1991b). For example, analyses of soot samples from a Binghamton, New York office building fire detected 20 μg/g of total CDDs (0.6 to 2.8 μg/g of 2,3,7,8-TCDD) and 765 to 2,160 μg/g of total CDFs with 12 to 270 μg/g of 2,3,7,8-TCDF. At that site, the fire involved the combustion of a mixture containing PCBs (65 percent) and chlorobenzene (35 percent). Hutzinger and Fiedler (1991b) also reported that laboratory analyses of soot samples from a PCB transformer fire which occurred in Reims, France indicated total CDD and CDF levels in the range of 4 to 58,000 ng/g and 45 to 81,000 ng/g, respectively.

The use of PCBs in new transformers in the United States has been banned and their use in existing transformers is being phased out. Because of the accidental nature of transformer fires it is not possible to accurately estimate annual emissions from this source.

3.6.19. Pyrolysis of Brominated Flame Retardants

The pyrolysis and photolysis of brominated phenolic derivatives and polybrominated biphenyl ethers used as flame retardants can generate polybrominated dibenzo-p-dioxins (BDDs) and dibenzofurans (BDFs) (Hutzinger and Fiedler, 1991a; Luijk et al., 1992; Watanabe and Tatsukawa, 1987). Watanabe and Tatsukawa (1987) observed the formation of BDFs from the photolysis of decabromobiphenyl ether. Approximately 20 percent of the decabromobiphenyl ether was converted to BDFs in samples that were irradiated with ultraviolet light for 16 hours (Watanabe and Tatsukawa, 1987). Decabromobiphenyl ether is used as a flame retardant in resins, textiles, and paints.

Luijk et al.(1990) studied the formation of BDD/Fs during the compounding/ extrusion of decabromodiphenyl ether into high-impact polystyrene polymer at 275°C. HpBDF and OBDF were formed during repeated extrusion cycles, and the yield of BDFs increased as a function of the number of extrusion cycles (Luijk et al., 1990). HpBDF increased from 1.5 to 9 ppm (in the polymer matrix) and OBDF increased from 4.5 to 45 ppm after four extrusion cycles.

Thoma and Hutzinger (1989) observed the formation of BDFs during combustion experiments with polybutylene-terephthalate polymers containing 9 to 11 percent decabromodiphenyl ether. Maximum formation of BDFs occurred at 400 to 600°C with a BDF yield of 16 percent. Although Thoma and Hutzinger (1989) did not provide specific quantitative results for similar experiments conducted with octabromodiphenyl ether and 1,2-bis(tri-bromophenoxy)ethane, they did report that BDDs and BDFs were formed.

Insufficient data are available upon which to derive annual BDD/BDF emission estimates from this source.

3.6.20. Carbon Reactivation Furnaces

Granular activated carbon (GAC) is an adsorbent that is widely used to remove organic pollutants from wastewater and in the treatment of finished drinking water at water treatment plants. Activated carbon is manufactured from the heat treatment of nut shells and coal under pyrolytic conditions (Buonicore, 1992a). The properties of GAC make it ideal for adsorbing and controlling vaporous organic and inorganic chemicals entrained in combustion plasmas, as well as soluble organic contaminants in industrial effluents and drinking water. The high ratio of surface area to particle weight (e.g., 600 - 1600 m^2/g), combined with the extremely small pore diameter of the particles (e.g., 15-25 Angstroms) increases the adsorption characteristics (Buonicore, 1992a). GAC will eventually become saturated and the adsorption properties will significantly degrade. When saturation occurs, the GAC usually must be replaced and discarded, which significantly increases the costs of pollution control. The introduction of carbon reactivation furnace technology in the mid-1980s created a method involving the thermal treatment of used GAC to thermolytically desorb the synthetic compounds and restore the adsorption properties for reuse (Lykins et al., 1987).

The used GAC can contain compounds that are precursors to the formation of CDDs/Fs during the thermal treatment process. The U.S. EPA measured precursor compounds in spent GAC used as a feed material to a carbon reactivation furnace tested during the National Dioxin Study (U.S. EPA, 1987). The total chlorobenzene content of the GAC ranged from 150 ppb to 6,630 ppb. Trichlorobenzene was the most prevalent species present, with smaller quantities of di- and tetra-chlorobenzenes detected. Total halogenated organics were measured to be about 150 ppm.

The U.S. EPA has stack tested two GAC reactivation furnaces for the emission of dioxin (U.S. EPA, 1987; Lykins et al., 1987). One facility was an industrial carbon reactivation plant, and the second facility was used to restore GAC at a municipal drinking water plant. The industrial carbon regeneration plant processed 36,000 kg/day of spent GAC used in the treatment of industrial wastewater effluents. Spent carbon was reactivated in a multiple-hearth furnace, cooled in a water quench and, stored and shipped back to primary chemical manufacturing facilities for reuse. The furnace fired natural gas,

and consisted of seven hearths arranged vertically in series. The hearth temperatures ranged from 480°C to 1000°C. The spent GAC contained about 40 percent weight moisture. The used GAC was fed to the top hearth. In the furnace, the spent carbon was dried and the organics adsorbed onto the carbon particles were volatilized and burned in the heated combustion atmosphere. The regenerated carbon dropped from the bottom hearth of the furnace to a quench tank to reduce the temperature. Air pollutant emissions were controlled by an afterburner, a sodium spray cooler, and a fabric filter. Temperatures in the afterburner were about 930°C.

The second GAC reactivation facility tested by U.S. EPA consisted of a fluidized-bed furnace located at a municipal drinking water treatment plant (Lykins et al., 1987). The furnace was divided into three sections: a combustion chamber, a reactivation section and a dryer section. The combustion section was fired by natural gas, and consisted of a stoichiometrically balanced stream of fuel and oxygen. These expanding gases of combustion provided heat and suspended and fluidized the carbon. Temperatures of combustion were about 1,038°C. The reactivation section outside the combustion chamber allowed for the complete volatilization of the heated GAC. Off-gasses from the reactivation/combustion section were directed through an acid gas scrubber and high-temperature afterburner prior to discharge from a stack.

The industrial GAC reaction furnace test data indicate that an average of 5.87E-02 μg of CDD/CDF per kg of GAC incinerated may be emitted from the stack during operation (U.S. EPA, 1987). An average of 2.98E-03 μg TEQ per kg of GAC may be released to the air during operation. A "medium" confidence rating is given to these emission factors, because only one industrial GAC reactivation furnace operating in the United States has been stack tested. In the second GAC reactivation furnace tested by EPA (Lykins et al., 1987), measurable concentrations of dioxin-like compounds were detected in the stack emissions. When chlorine was used in pretreatment of the surface water for preliminary disinfection prior to filtration with GAC, the 2,3,7,8-TCDD congener was seen in the particulate stack emission discharges to the incinerator afterburner in low concentration [0.001-0.02 parts per trillion by volume (ppt/v)]. 1,2,6,7-TCDF was detected in two out of four stack tests in a concentration range of 0.004-0.02 ppt/v. When no chlorine was

used to disinfect the surface water prior to filtration with GAC, no 2,3,7,8-TCDD was detected (<0.001 ppt/v). With the afterburner operating, no CDD congeners below HpCDD were detected in the stack emissions. Concentrations of HpCDDs and OCDD ranged from 0.001 to 0.05 ppt/v and 0.006 to 0.28 ppt/v, respectively. All congener groups of CDFs were detected in the stack emissions even with the afterburner operating. Total CDFs emitted from the stack averaged 0.023 ppt/v. Measurements of the individual CDD/CDF congeners were not performed, therefore it was not possible to derive emission factors for this facility.

The mass of GAC that is reactivated annually in carbon reactivation furnaces is not known. However, a crude estimate, which is given a "low" confidence rating, is the mass of virgin GAC shipped each year by GAC manufacturers. According to U.S. DOC (1990c), 48 thousand metric tons of GAC were shipped in 1987. Applying the emission factors developed above to this crude estimate of potential GAC reactivation volume, annual releases of 0.14 grams of TEQ and 2.8 grams of total CDD/CDF are estimated. Based on the "medium" confidence rating assigned to the emission factor, the estimated range of potential annual emissions is assumed to vary by a factor of 5 between the low and high ends of the range. Assuming that the best estimate of annual emissions (0.14 g TEQ/yr) is the geometric mean of this range, the range is calculated to be 0.06 to 0.3 g TEQ/yr.

3.6.21. Cement Kilns

Portland cement is a fine, grayish powder consisting of a mixture of four basic materials: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). Pyroprocessing in a rotary-type kiln plays a central role in fusing the basic raw materials into cement. The raw materials are ground into fine particles and are then either suspended in water to form a pumpable slurry (i.e., wet process) or are fed directly (i.e., dry process) into a rotary kiln for processing at elevated temperatures in an oxygen-enriched atmosphere. In the rotary kiln, evaporation of the water, calcination of the carbonate constituents, and fusion of the minerals occurs to form clinker. Clinker is a gray-colored, glass-hard material comprised of the cement minerals, dicalcium silicate, tricalcium silicate, calcium aluminate, and tetracalcium aluminoferrite. The clinker is then

ground into a fine powder and mixed with gypsum to form portland cement. Approximately 1,575 kg of dry raw materials are needed to produce about 1000 kg of cement clinker (Greer et al., 1992). In 1991, the last year in which data is available, about 66 billion kg of cement clinker was produced in the United States by 212 portland cement kilns requiring about 103 billion kg of raw materials (U.S. EPA, 1993f; Greer et al.,1992).

Because of the relatively high combustion temperature required to produce cement clinker (1400° to 1510°C), coal or petroleum coke are typically used as the primary fuel to sustain combustion in the kiln. However, some cement kilns do burn hazardous liquid and solid waste as supplemental fuel to reduce the amount of coal that is purchased. It is estimated that 34 of the 212 existing cement kilns (i.e., 16 percent) burn hazardous waste as supplemental fuel (U.S. EPA, 1993f). Other types of non-hazardous liquid and solid wastes used as supplemental fuels include tires, waste oil, and wood chips. The most common air pollution control devices (APCD) employed on rotary kilns are those intended to control dust and particulate matter (i.e., fabric filters and/or electrostatic precipitators). Dioxins were first detected in stack emissions from portland cement kilns in the early 1980s (U.S. EPA, 1987; Peters, 1983; Branscome et al. 1984, 1985). Dioxin was detected only in low amounts and was thought to be caused by the co-firing of liquid hazardous waste with conventional fossil fuels (Peters, 1983). The EPA gave this source category a low priority for follow-up testing in EPA's National Dioxin Study conducted in 1985-1986 (U.S. EPA, 1987). Since then, the thermolytic reactions and the conditions favoring the formation of CDDs and CDFs in combustion processes have become better understood. (See Section 3.5). Some aspects of this theory warrant investigation into the formation of dioxin in portland cement kilns, including:

- Some primary combustion fuels (i.e., coal and petroleum coke) and fuel supplements (wood chips and tires) used to sustain elevated temperatures in the kiln to form clinker may also produce aromatic hydrocarbon compounds (e.g., benzene, phenol) that can later become chlorinated ring structures. The oxidation of HCl gas has been

shown to provide chlorine available for ring substitution. In addition, chlorine has been measured directly in the combustion fuels to cement kilns (EER, 1993).

- The chlorinated aromatic compounds may act as precursor molecules to the thermalytic formation of CDD/CDFs on the active surface of carbonaceous particulates;
- De novo synthesis of CDD/CDFs on the active surface of carbonaceous particulates in the presence of a catalytic agent (e.g., a metal ion such as copper chloride);
- Post-kiln temperatures of the combustion gases in the APCD system are within the range of temperatures observed in laboratory studies that promote the continued formation of CDD/CDFs (i.e., 250° to 350°C); and
- Co-firing of liquid hazardous organic wastes with coal and petroleum coke may lead to an increase in the amount of CDD/CDFs formed in the post-combustion zone.

Currently, cement kilns that accept and burn hazardous waste as an auxiliary fuel are required under RCRA to characterize pollutant stack emissions, including emissions of CDD/CDFs. EPA's Office of Solid Waste is in the process of collecting and analyzing these emission reports to determine the extent and magnitude of CDD/CDF releases and the need for further regulation. Preliminary stack test data are available from 14 of the 34 cement kilns burning hazardous waste and from 3 of the 178 kilns not burning hazardous waste (EER, 1993; RTI, 1993). Table 3-35 is a summary of the available emissions data. For kilns accepting and burning hazardous waste as supplemental fuel, it appears that the concentration of dioxin in the stack gas (grams/dscm at 7 percent O_2) is highly variable. For example, the average stack emissions of total CDD/CDF for individual kilns range from 2 to 2000 ng/dscm, a thousand-fold difference. There appears to be no consistent pattern to the relationship of total CDD/CDFs to the estimated dioxin TEQ, indicating a wide variability in the distribution of toxic congeners of CDDs and CDFs in the emissions. For example, the ratio of total CDD/CDFs to the TEQ ranges from about a factor of 5:1 to a factor of 1000:1, indicating that some kilns have a congener distribution skewed toward the lower chlorinated more toxic congeners and others are skewed toward the higher chlorinated less toxic congeners. Cement kilns which do not burn hazardous waste as supplemental fuel appear to be less variable. However, this observation must be tempered

Table 3-35. Concentrations of Total CDD/CDFs and Dioxin TEQ (grams/dscm) Measured at the Stack of Portland Cement Kilns Burning and Not Burning Hazardous Waste As Supplemental Fuel[a]

I. Cement Kilns Burning Hazardous Waste						II. Cement Kilns Not Burning Hazardous Waste				
Facility	APCD	CDD/CDF Emission (g/dscm)	TEQ Emission (g/dscm)	Ratio Total/TEQ	No. of Tests	Facility	APCD	CDD/CDF Emission (g/dscm)	TEQ Emission (g/dscm)	No. of Tests
A	ESP	2.300e-07	1.283e-09	179.3	8	O	ESP	NA	6.929e-10	1
B	ESP	3.260e-07	3.800e-09	85.8	4	P	ESP	NA	3.188e-11	2
C	ESP	1.043e-08	3.178e-10	32.8	9	Q	ESP	NA	1.996e-09	2
D	ESP	5.525e-07	3.828e-09	144.3	2					
E	ESP	NA	4.533e-10	NA	6			Mean	9.068e-10	
F	ESP	4.118e-09	6.045e-10	6.8	6			Std	8.158e-10	
G	ESP	1.983e-09	1.750e-11	113.3	4					
H	ESP	6.765e-07	4.455e-09	151.9	2					
I	ESP	1.998e-06	4.091e-08	48.8	2					
J	FF	9.779e-08	8.300e-11	1178.2	1					
K	FF	2.100e-09	1.422e-10	14.8	1					
L	FF	2.467e-07	4.318e-08	5.7	1					
M	FF	NA	5.702e-11	NA	4					
N	FF	1.677e-08	2.067e-10	81.1	2					
	Mean	3.469e-07	7.096e-09							
	Std	5.673e-07	1.490e-08							

Sources: Data compiled from EER (1993) and RTI (1993).

[a] Notes:

1. Names and locations of tested facilities are not given in order to preserve confidentiality.
2. APCD refers to Air Pollution Control Devices.
3. (g/dscm) is grams per dry standard cubic meter measured at 20°C, 1 atm corrected to 7 percent O_2.
4. No. of tests is the number of separate stack tests performed at a facility to derive the average estimate.
5. ESP is an electrostatic precipitator.
6. FF is a fabric filter.
7. CDD/CDF is the total emission of tetra- through octa- CDDs and CDFs.
8. TEQ is the dioxin toxic equivalents calculated using the International Toxic Equivalency Procedure.
9. Mean is the arithmetic average.

by the fact that fewer of these kilns have been stack tested.

The limited emission data suggests that the average stack concentrations of CDD/CDFs are about eight times higher among the kilns burning hazardous waste than those that do not. As discussed below, a similar relationship was seen in the cement kiln dust samples from these two categories of kilns. On this basis, it was decided that separate emission factors should be developed for the kilns burning hazardous waste and those that do not. Given the limited emission test data, especially among the kilns that do not burn hazardous waste, clearly more testing is needed to confirm this difference in emission factors.

National estimates of air emissions of dioxin TEQ/yr from all operating cement kilns were made using two different methods:

1. Dioxin emissions correlate with the total mass of materials processed and burned at the kiln to form clinker (i.e., related to the kiln throughput); and

2. Dioxin emissions correlate with the total energy content of the fuel (including hazardous waste) used to sustain combustion in the kiln.

Although these two methods would likely generate different emission estimates if site-specific data (i.e., throughput and energy consumption data) were available, such data were not available for this report and, therefore, the use of generic industry average data resulted in identical estimates.

For the first method, three values must be known in order to calculate annual dioxin TEQ emissions: (a) the average concentration of dioxin TEQ in the stack gas (g TEQ/dscm); (b) the average volume of combustion gas evolved per kg of material fed to the kiln; and (c) an estimate of the total dry weight of materials processed by all operating cement kilns (kg/yr). Average dioxin TEQ stack emission concentrations are presented in Table 3-35 for kilns burning and not burning hazardous waste as supplemental fuel. The averaging gave equal weighting to all tested kilns. The average dioxin TEQ stack concentrations are 7.1 ng/dscm and 0.9 ng/dscm for kilns burning hazardous waste and

not burning hazardous waste, respectively. A reasonable estimate of combustion gas volume/kg of materials processed in the kiln is 1.75 dscm/kg (RTI, 1993). This approach suggests an emission factor of 12.4 ng TEQ/kg and 1.6 ng TEQ/kg for kilns burning and not burning hazardous waste, respectively.

Greer et. al (1992) estimated that the ratio of the dry weight of materials charged into the kiln to the weight of dry clinker produced is 1.575:1. Therefore, if 66 billion kg of clinker were produced by 212 cement kilns in 1991 (U.S. EPA, 1993f), then 104 billion kg of raw materials were consumed in that year. A final assumption is that the annual throughput of raw materials processed is roughly proportional to the number of kilns in the class of cement kilns (i.e., the number burning hazardous waste versus the number of facilities not burning hazardous waste). Multiplying the emission factors by the raw material throughput yields annual emission estimates of 210 g TEQ for kilns burning hazardous waste and 140 g TEQ for kilns not burning hazardous waste.

For the second method, it is assumed that the dioxin emissions are better calculated on the basis of annual fuel consumption rather than the annual amount of materials processed by the kiln. Given the diversity and mixtures of fuel types typically used (coal, coke, liquid hazardous waste, natural gas, oil, wood chips, tires), a good measurement of total fuel consumption is the amount of total energy consumed to produce the clinker (U.S. EPA, 1993f). Johnson (1992) estimated that 71 trillion kcals were consumed in the year 1991 by all operating portland cement kilns. Dividing this value by the total kg of raw material processed (is 104 billion kg, as reported above) yields an average energy usage of 680 kcal/kg of raw material. Dividing this value into the emission factors derived above (in units of ng of dioxin TEQ/kg of raw material) yields emission factors in terms of ng of dioxin per kcal. This approach suggests an emission factor of 2.3 pg of TEQ/kcal for kilns not burning hazardous waste and 18 pg of TEQ/kcal for kilns which do burn hazardous waste. Finally, it is assumed that the total energy usage can be apportioned between kilns burning hazardous waste (34 of 212 kilns) and those that do not (178 of 212 kilns) on the basis of the number of kilns in each group. Multiplying these energy use estimates by the energy based emission factors yields the

following estimates of annual emissions: 210 g TEQ for kilns burning hazardous waste and 140 g TEQ for kilns not burning hazardous waste.

Both of these methods suggest that annual dioxin emissions to air from all cement kilns combined is about 350 grams TEQ. The estimated TEQ emission factors used to derive this best estimate of annual TEQ emissions are given a "low" confidence rating because the mechanisms giving rise to dioxin emissions from cement kilns are largely unknown; very few of the existing facilities have been stack tested for emissions; and because of the apparent high variability in the ratio of total CDD/CDFs to dioxin TEQ and the apparent high variability in emissions between tested facilities as shown by the large standard deviation in Table 3-35. The "production" estimate of annual raw material throughput is given a "high" confidence rating because it is based on recent survey data. Based on these confidence ratings, the estimated range of potential emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the lowest estimate of annual emissions (350 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 110 to 1,100 g TEQ/yr.

In a recent Report to Congress (U.S. EPA, 1993f), EPA's Office of Solid Waste establishes the factual basis for its decision making regarding the appropriate regulatory status, under RCRA, of cement kiln dust (CKD) waste. To aid EPA in their study, the Portland Cement Association (PCA) conducted a survey in 1991 of cement manufacturers. Survey responses were received from 64 percent of the active cement kilns in the United States. Based on the survey responses, EPA estimated that the U.S. cement industry generated about 12.9 million metric tons of gross CKD and 4.6 million metric tons of "net CKD", of which 4.2 million metric tons was land disposed, in 1990. The material collected by the APCD system is called "gross CKD" (or "as generated" CKD). The gross CKD is either recycled back into the kiln system or is removed from the system for disposal (i.e., "net CKD" or "as managed" CKD) (U.S. EPA, 1993f).

Also in support of the Report to Congress, EPA conducted sampling and analysis during 1992 and 1993 of CKD and clinker. The purposes of the sampling and analysis efforts were: (1) to characterize the CDD/CDF content of clinker and CKD ; (2) to determine the relationship, if any, between the CDD/CDF content of CKD and the use of

hazardous waste as fuel; and (3) to determine the relationship, if any, between the CDD/CDF content of CKD and the use of wet versus dry process cement kilns. Clinker samples from 9 kilns and CKD samples from 11 kilns (six of which burn hazardous waste) were analyzed (U.S. EPA, 1993f).

CDD/CDFs were not detected in any of the clinker samples. Tetra- through octa-chlorinated CDDs and CDFs were detected in the "gross CKD" samples obtained from 10 of the 11 kilns and in the "net CKD" samples obtained from 8 of the 11 kilns. The CDD/CDF content of "gross CKD" ranged from 0.008 to 247 ng TEQ/kg and for "net CKD" the content ranged from 0.045 to 195 ng TEQ/kg. Analyses for seven PCB congeners were also conducted but no congeners were detected in any clinker or CKD sample. TCLP leachate testing of the CKD samples from six kilns showed no leaching of CDD/CDFs (detection limits ranged from 3 to 37 pg/L) except for OCDD in two samples (110 and 170 pg/L). Statistical analysis of the results indicated that mean CDD/CDF concentrations in "net CKD" generated by the sampled kilns burning hazardous waste are higher (35 ng/kg) than in "net CKD" generated by the sampled facilities not burning hazardous waste (3.0E-02 ng/kg). These calculations of mean values treated not detected values as zero. If the not detected values had been excluded from the calculation of the means, then the mean value for "net CKD" from kilns burning hazardous waste would increase by a factor of 1.2 and the mean value for "net CKD" from kilns not burning hazardous waste would increase by a factor of 1.7. One sampled kiln had CDD/CDF concentrations more than two orders of magnitude greater than the TEQ levels found in samples from any other kiln. If this kiln is considered to be atypical of the industry (U.S. EPA, 1993f) and is not included in the calculation, then the mean "net CKD" concentration for hazardous waste burning kilns decreases to 2.9 ng/kg.

From these data, an estimate of dioxin TEQ emissions to land in the form of land-disposed "net CKD" can be made. The estimate of land-disposed CKD from the 1991 PCA Survey, 4.2 million metric tons per year (basis year is 1990), was divided among kilns burning hazardous waste (34 kilns) and those which do not (178 kilns) on the basis of the number of kilns in each category. The average TEQ concentration in the net CKD from kilns burning hazardous waste, including the potentially non-typical kiln, was 35 ng

TEQ/kg. For kilns which do not have hazardous waste the average concentration in the "net CKD" was 3.0E-02. Multiplying these average concentrations by the annual "net CKD" production, yields estimates of 24 g TEQ/yr for kilns burning hazardous waste and 0.1 g TEQ/yr for kilns not burning hazardous waste, yielding a total of 24.1 g TEQ/yr for all kilns. The "production" estimate was assigned a "high" confidence rating because it is based on recent EPA survey data. The "emission factor" estimates are assigned a "low" confidence rating because the sampling data upon which they are based showed high variability among the 11 kilns sampled (out of 212 kilns in the United States). Based on these confidence ratings, the estimated range of potential annual emissions is assumed to vary by a factor of 10 between the low and high ends of the range. Assuming that the best estimate of annual emissions (24.1 g TEQ/yr) is the geometric mean of this range, then the range is calculated to be 7.6 to 76 g TEQ/yr.

3.6.22. Additional Combustion and High Temperature Sources

Although discussed as potential sources in the preceding sections, insufficient data are available upon which to develop emission factors for the primary ferrous and primary nonferrous metal refining/smelting industries. In addition, although emission estimates were developed in Section 3.6.13 for diesel-powered on-highway vehicles (i.e., the largest use of diesel fuel in the United States), because of insufficient data no estimates were developed for off-highway transportation diesel engine fuel use (including railroad engine fuel and fuel for agricultural machinery) or for diesel fuel use by the commercial and industrial sectors of the economy. Also, although no estimated emissions could be developed for residential oil, gas, and charcoal combustion because of lack of emission rate factors, these have been identified as potential sources by Harrad et al. (1992a, 1992b) and Fiedler and Hutzinger (1991b).

3.7. RESERVOIR SOURCES

It is very difficult to estimate CDD/CDF releases that may be occurring from reservoir sources. However, some idea of the potential magnitude of these emissions can be gained by estimating the size of the overall reservoir. Equation 1 calculates the

concentration of a contaminant in a reservoir given the deposition rate of the contaminant into the reservoir and the rate of dissipation from that reservoir:

$$C = \frac{DEP\ (\ 1\ -\ e^{kt}\ )}{k\ MIX} \qquad \text{(Eqn. 3-1)}$$

where C is the concentration after time t, DEP is the deposition rate (in units of mass/area-time), k is the first order dissipation rate (time^{-1}), and MIX is the mass of the reservoir into which DEP mixes (mass units, corresponding to area of DEP). Consider the case where DEP has been occurring for a number of years at a steady rate. A question that might be asked is, what is the contribution of a year's worth of deposition to the amount that is already there. This can be estimated with a ratio of estimated concentrations C_1/C_2 using Equation (1), where C_1 is the concentration after the number of years, and C_2 is the year's worth of deposition. Assuming DEP, MIX, and k are constant, the ratio of C_1/C_2 reduces to:

$$\frac{1\ -\ e^{-k\,t_1}}{1\ -\ e^{-k\,t_2}} \qquad \text{(Eqn. 3-2)}$$

where t_1 is the number of years that DEP has been occurring, and t_2 is equal to 1 for the one year's worth of deposition. For the sake of this discussion, if one assumes that DEP for dioxin-like compounds has been steady since the 1940s, and one wants to evaluate a year's worth of deposition in the 1990s, then t_1 equals about 50 years. A dissipation rate of 0.0693, corresponding to a 10-year half-life was used for atmospheric deposition onto soils for the methodologies described in Volume III. A t_1 of 50 and k of 0.0693 applied to Equation (2) yields a ratio of about 14.5. This means that there would be about 14.5 times more contaminant in the reservoir than one year's contribution.

However, the half-life of 10 years is probably too low for this exercise. This half-life was generated from data on 2,3,7,8-TCDD applied to experimental plots as 2,4,5-T in Agent Orange testing (Young, 1983). This might be appropriate for dissipation from a bounded area of high soil contamination, where dissipation mechanisms such as soil erosion, dust resuspension, or volatilization might be occurring. However, if MIX is considered as the total reservoir of soil and surface vegetation, then losses from a bounded area are unlikely to translate to losses from the larger system. In other words, a more appropriate half-life for this discussion might be more like 50 years than 10 years. If 50 years is assumed in the above exercise, than the ratio increases to 36.

This analysis suggests that dioxin-like compounds already in the reservoir source may exceed annual contributions to the reservoir source by 15 or more times. The potential for emissions from this large source is uncertain. Dioxin-like compounds that accumulate in deep sediments or become buried in the soil are not likely to contribute to current emissions. However, those located near the surface could become re-entrained into the air or water bodies.

3.8. COMPARING SOURCE EMISSIONS TO DEPOSITION ESTIMATES

As discussed in Section 3.1, several investigators have attempted to conduct "mass balance" checks on the estimates of national dioxin releases to the atmosphere. Basically, this procedure involves comparing estimates of the emissions to estimates of aerial deposition. Such studies in Sweden and Great Britain have suggested that the deposition exceeds the estimated emissions by about 10-fold. These studies are acknowledged to be quite speculative due to the strong potential for inaccuracies in the emission and/or deposition estimates. In addition, the apparent discrepancies could be explained by long range transport from outside the country, resuspension and deposition of reservoir sources, atmospheric transformations, or unidentified sources. Bearing these limitations in mind, this procedure has been used below to compare the estimated emissions and deposition in the U.S.

Koester and Hites (1992) measured both wet and dry deposition of CDD/CDFs at two locations in Indiana. These measurements indicate a range of 370 to 540 ng/m^2-yr on

a total CDD/CDF basis. If perfect congener distribution is assumed for the Koester and Hites measurements, these total deposition rates correspond to about 1 to 2 ng TEQ/m^2-yr. Based on studies of temporal trends in CDD/CDF concentrations in sediments from Green Lake, a non-industrially impacted lake near Syracuse, New York, Smith et al. (1993) have calculated the total CDD/CDF atmospheric deposition rate to be 375 ng/m^2-yr for the period 1986 to 1990 which is very similar to that reported by Koester and Hites (1992). Andersson et al. (1992) estimated a deposition rate of 1 ng TEQ/m^2-yr on the basis of snow measurements in Northern Sweden.

Fernandez et al. (1992) measured the wet and dry deposition over a period of one month at an urban/semiurban location in Great Britain. Assuming that the deposition measured over the one month period is representative of an entire year, then the rate of deposition is 13 ng TEQ/m^2-yr (setting nondetects equal zero) or 17 ng TEQ/m^2-yr (setting nondetects at half the detection limit). Van Jaarsveld and Schutter (1992), using long range transport modelling, estimate that national average deposition rates in Northern European countries are in the range of 1 to 10 ng TEQ/m^2-yr.

In 1992, Hiester et al. (1993) collected two month duration deposition samples in seven urban and one rural location in Germany. The total CDD/CDF deposition rates ranged, on an annualized basis, from 246 to 1,687 ng/m^2-yr at the urban locations and 420 ng/m^2-yr at the rural location. The TEQ deposition rates ranged from 3.6 to 30.3 ng TEQ/m^2-day at the urban locations and 4.4 ng TEQ/m^2-day at the rural location. For these calculations, Hiester et al. (1993) set nondetects equal to zero.

Liebl et al. (1993) reported the results of long term deposition measurements at three locations in Germany: a rural region with some industry, a rural "background" site, and an industrial/living area site. The deposition rates, based on 11 months of measurement in 1992, were reported as 1.1 ng TEQ/m^2-yr for the rural background site, 1.5 ng TEQ/m^2-yr for the rural/industrial site (estimated from figure in the report), and 7.6 ng TEQ/m^2-yr for the industrial/living area site (estimated from figure in the report).

Fiedler (1993) reports that the average deposition rate for rural areas in Germany (defined as agriculture, forest, and water) is 4.4 TEQ/m^2-yr with a range of 1.8 to 7.3 ng TEQ/m^2-yr. The estimated deposition rate in industrialized areas typically ranges from 7.3

to 36 ng TEQ/m^2-yr with even higher deposition rates (up to 1,000 ng TEQ/m^2-yr) in a small number of areas.

Broman et al. (1991) collected a two-month duration deposition sample at a remote open coastal area in Sweden and reported a deposition rate for total CDD/CDFs of 38 ng/m^2-yr. Näf et al. (1992) measured the flux of CDD/CDFs to aquatic sediments at two remote background sites; one in the Bothnian Sea and the other in the Baltic Sea. The measured rates for total CDD/CDFs ranged from 240 to 1,200 ng/m^2-yr and for TEQ ranged from 3 to 14 ng TEQ/m^2-yr. Atmospheric deposition was presumed by the authors to be the principal source of the measured flux because the sampling sites were located far from coastal areas, freshwater input sources, and industrial input.

For purposes of generating a preliminary estimate of CDD/CDF deposition in the United States, it is assumed that the deposition rate of 1 ng TEQ/m^2-yr measured in Sweden applies to Alaska (land area = 1.5×10^{12} m^2). The average deposition rate for the continental United States (land area = $7.8 \times 10^{12} m^2$) could be as low as 2 ng TEQ/m^2-yr (based on limited U.S. data) or perhaps about 6 ng TEQ/m^2-yr (based on European data). Based on these assumptions, total U.S. deposition can be estimated as about 20,000 to 50,000 g TEQ/yr. This range can be compared to the range of estimated annual air emissions in the United States, 3,300 - 26,000 g TEQ/yr, as presented in Table 3-2. As noted above however, making and interpreting such comparisons is highly speculative considering the very limited data on emissions and deposition.

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4. LEVELS OF CDD, CDF, AND PCB CONGENERS IN ENVIRONMENTAL MEDIA AND FOOD

4.1. INTRODUCTION

Polychlorinated *dibenzo-p-dioxins* (CDDs), polychlorinated dibenzofurans (CDFs), and polychlorinated biphenyls (PCBs) have been found throughout the world in practically all media including air, soil, water, sediment, fish and shellfish, and other food products such as meat and dairy products. Also, not unexpectedly, considering the recalcitrant nature of these compounds and their physical/chemical properties (i.e., low water solubilities, low vapor pressures, and high K_{ow}s and K_{oc}s), the highest levels of these compounds are found in soils, sediments, and biota (ppt and higher); very low levels are found in water and air (ppq and lower). The widespread occurrence observed is not unexpected considering the numerous sources that emit these compounds into the atmosphere (discussed in Chapter 3), and the overall resistance of these compounds to biotic and abiotic transformation. (See Chapter 2.) Part-per-trillion levels of CDDs/CDFs have been found in everyday materials that are contaminated with dust--clothes dryer lint (2.4 to 6.0 ng TEQ/kg; vacuum cleaner dust (8.3 to 12 ng TEQ/kg); room air filters (27 to 29 ng TEQ/kg); and house furnace filter dust (170 ng TEQ/kg) (Berry et al., 1993). Although Berry et al. (1993) only analyzed one or two samples of these materials, the findings suggest that these compounds may be ubiquitous.

The purpose of this chapter is to provide an overview of the concentrations at which these compounds have been found in the environment and food based on data presented in the published literature. This literature summary is not all inclusive, but is meant to present the reader with a general overview of values reported in the recent literature. Only data from Government-sponsored monitoring studies and studies reported in the peer-reviewed literature are discussed in this chapter. Data are presented as they were presented in the original studies/reports. No attempt has been made to verify or assess the adequacy of the quality assurance/quality control measures employed in these studies beyond those described in the published reports. The final section of this chapter discusses the mechanisms by which these compounds could enter the food chain.

4.2. CONCENTRATIONS IN SOIL

Tables B-1 and B-2 (Appendix B) contain summaries of data from several of the numerous studies in the published peer-reviewed literature regarding concentrations of CDDs and CDFs in soil. Data on coplanar PCB congener soil concentrations were not found in the literature; the PCB soil concentration data found in the literature were reported as either total PCB concentrations or concentrations of Aroclor PCB mixtures. Descriptions of several of the studies summarized in Appendix B are presented below.

4.2.1. North American Data

Soil sampled in 1987 from the vicinity of a sewage sludge incinerator was compared with soil from rural and urban sites in Ontario, Canada, by Pearson et al. (1990). Soil in the vicinity of the incinerator showed a general increase in CDD concentration with increasing degree of chlorination. Of the CDFs, only OCDF was detected (mean concentration 43 ppt). Rural woodlot soil samples contained only OCDD (mean concentration of 30 ppt). Soil samples from undisturbed urban parkland settings revealed only HpCDDs and OCDD, but all CDF congener groups (Cl_4 to Cl_8) were present. Those samples showed an increase in concentration from the HpCDDs to OCDD and PeCDFs to OCDD. The TCDFs had the highest mean value (29 ppt) of all the CDF congener groups. Resampling of one urban site in 1988, however, showed high variability in the concentrations of CDDs and CDFs.

Data were collected on CDD and CDF levels in soil samples from industrial, urban, and rural sites in Ontario and some U.S. Midwestern States (Birmingham, 1990). The levels of CDD/CDF in rural soils were primarily nondetected (ND), although the HpCDDs and OCDD were found in a few samples. In urban soils, the tetra- through octa-congener groups were measured for both CDDs and CDFs. The HpCDDs and OCDD dominated the homologue profile and were two orders of magnitude greater than in the rural soils. These soils also contained measurable quantities of the TCDDs and PeCDDs. Industrial soils did not contain any TCDDs or PeCDDs, but they contained the highest levels of the TCDFs, HpCDFs, and OCDF. In another study, soils from industrialized areas of a group of cities from Midwestern and Mid-Atlantic States (Michigan, Illinois, Ohio, Tennessee,

Pennsylvania, New York, West Virginia, Virginia) were analyzed for levels of 2,3,7,8-TCDD (Nestrick et al., 1986). Many of the samples were taken within 1 mile of major steel, automotive or chemical manufacturing facilities, or municipal solid waste incinerators. Concentrations of 2,3,7,8-TCDD measured in this study ranged from ND to 9.4 ppt.

EPA conducted a 2-year nationwide study to investigate the national extent of 2,3,7,8-TCDD contamination (U.S. EPA, 1987). The results of this large study were summarized broadly in the primary reference (i.e., the number and types of samples per site and range of detection). The method used to analyze samples for five of the seven "tiers" of the study had a detection limit in soil, sediment, and water of 1 part per billion (ppb). [Each "tier" of sites is a grouping of sites with a common past or present use (e.g., industrialized, pristine, etc.)]. Only Tier 5 (sites where pesticides derived from 2,4,5-trichlorophenol (TCP) have been or are being used for commercial purposes), and Tier 7 (ambient sampling for fish and soil) had detection limits of 1 ppt. Consequently, the data from this study are not included in the tables, but some observations from this study with regard to soil contamination are discussed below.

Soil concentrations found in most of the 100 Tier 1 and 2 sites (i.e., sites already on or expected to be on the NPL list) were in the ppb range; although in a few sites where concentrated 2,4,5-TCP production wastes were stored or disposed, concentrations were as high as 2,000 parts per million (ppm). Offsite soil contamination of concern was confirmed in 7 of the 100 Tier 1 and 2 sites, with soil concentrations in the ppb range. Eleven of 64 Tier 3 sites (facilities and associated disposal sites where 2,4,5-TCP and its derivatives were formulated into pesticide products) were found to have soil concentrations exceeding 1 ppb, and in 7 of 11 sites where contamination was found, only one or two soil samples were above 1 ppb. Fifteen of 26 Tier 5 sites (areas where 2,4,5-TCP and pesticide derivatives had been or were being used) had concentrations above 1 ppt, and one of those had a single detection of 6 ppb. Two-thirds of all detections at the Tier 5 sites were below 5 ppt. Three of 18 Tier 6 sites (organic chemical and pesticide manufacturing facilities where improper quality control on production processes could have resulted in 2,3,7,8-TCDD being introduced into the wastestreams) had soil concentrations that exceeded the detection limit of 1 ppb, although these levels

were limited to one or two samples per site. Seventeen of the 221 urban soil sites and 1 of the 138 rural sites from Tier 7 (background sites not expected to have contamination) had soil concentrations exceeding 1 ppt. The highest concentration detected (11.2 ppt) was found in an urban sample. The results from Tier 7 are consistent with the other studies discussed above regarding soil concentrations of 2,3,7,8-TCDD in nonindustrial settings.

4.2.2. European Data

Soil samples from rural and semi-urban sites in England, Wales, and lowland Scotland showed a general increase in concentration from the TCDDs to OCDD, whereas the CDF levels showed very little variation between the congener groups (Creaser et al., 1989). Concentrations of 2,3,7,8-TCDD at those sites ranged from <0.5 to 2.1 parts per trillion (ppt). The median values for the TCDDs to OCDD were 6.0, 4.6, 31, 55, and 143 ppt, respectively. The median values for the TCDFs to OCDF were 16, 17, 32, 15, and 15 ppt. Evaluation of soil data from urban sites in the same geographical area showed that the mean levels for the CDD and CDF congeners were significantly greater ($p<0.01$) than those for rural and semi-urban background soils (Creaser et al., 1990). Concentrations of 2,3,7,8-TCDD at the urban sites ranged from <0.5 to 4.2 ppt. The median values for the TCDDs to OCDD were 40, 63, 141, 256, and 469 ppt, respectively. The median values for the TCDFs to OCDF were 140, 103, 103, 81, and 40 ppt. The significantly elevated levels of the lower congeners, together with higher overall CDD/CDF concentrations, are indicative that local sources and short-range transport mechanisms are major contributors of CDDs and CDFs to urban soils.

Analysis of four sites in Hamburg, Germany, contaminated by an organochlorine pesticide manufacturing company showed patterns of CDD and CDF distribution that are similar to the urban and industrial sites examined in England, Wales, and Scotland (Sievers and Friesel, 1989). The study indicated that CDDs and CDFs showed a regular increase in concentration with increasing degree of chlorination (although individual data points were not presented). The maximum concentrations of 2,3,7,8-TCDD ranged from 900 ppt to

874,000 ppt. The very high concentrations of 2,3,7,8-TCDD at the sites were attributed to an admixture of wastes from 2,4,5-T production.

A soil sampling survey in Salzburg, Austria, also showed that the concentrations of CDD/CDFs were higher in urban and industrial sites than in rural sites (Boos et al., 1992). The total CDD content of the soils ranged from 33.7 to 1236.7 ppt for urban sites; 92.2 to 455 ppt for industrial sites; and 7.1 to 183.6 ppt for rural sites. The total CDF content of the soils ranged from 45.6 to 260.8 ppt for urban sites; 53.0 to 355.3 ppt for industrial sites; and 12.0 to 77.7 ppt for rural sites.

Rotard et al. (1993) measured CDD/Fs in soil samples collected from forest, grassland. and plowland sites in western Germany. The highest mean concentration of CDD/Fs were found in the sursoil and topsoil layers of deciduous (38.0 ng TEQ/kg dry matter) and coniferous forests (36.9 ng TEQ/kg dry matter). Grassland and plowland sites had mean concentrations of 2.3 ng TEQ/kg dry matter and 1.7 ng TEQ/kg dry matter, respectively.

4.2.3. Soil Summary

Some general observations for CDD and CDF levels in soils are possible from the data presented in the various soil studies discussed above:

- Generalizations about the prevalence of specific congeners within a congener group are not possible.
- As the degree of chlorination increases, the concentrations increase. Concentrations of the hepta- and octa-chlorinated congeners are generally higher than the tetra-, penta-, and hexa-chlorinated congeners.
- Concentrations associated with industrial sites clearly are the highest, with concentrations in the hundreds to thousands of parts per trillion.
- Concentrations in settings identified as urban are higher than those in areas identified as rural.

Based on the above studies, 95 samples were selected as representing background conditions in the United States. The mean TEQ level was estimated to be 8 ppt assuming

that nondetects equal half the detection limit. Similarly, 133 background samples were selected from the European studies and were estimated to have a mean of 9 ppt of TEQ.

4.3. CONCENTRATIONS IN WATER

Tables B-3 and B-4 (Appendix B) contain summaries of data from the limited number of published studies regarding concentrations of CDDs and CDFs in water. Data on coplanar PCB congener water concentrations were not found in the literature. Several of these studies are discussed below.

4.3.1. North American Data

A survey of 49 drinking water supplies in Ontario, including supplies in the vicinity of chemical industries and pulp and paper mills, was initiated in 1983 (Jobb et al., 1990). As of February 1989, 4,347 congener analyses had been performed on 399 raw and treated water samples. OCDD was detected in 36 of 37 positive results and ranged from 9 to 175 ppq in raw samples (33 positive samples) and 19 to 46 ppq in treated samples (4 positive samples). These low concentrations were found primarily in water obtained downstream of industrialized areas in the St. Clair/Detroit River system. Concentrations of 2,3,7,8-TCDD were not detected in any sample. Because CDDs and CDFs are hydrophobic concentrations of compounds and consequently have a tendency to sorb onto particulate matter in water, conventional water treatment processes are expected to be effective in removing the contaminants along with the particulates. This is substantiated by the fact that 33 of the 37 positive results were raw water samples. Because of the relatively low levels of CDDs detected in the samples, it is difficult to ascertain whether the CDDs were particulate-associated or dissolved.

A survey of 20 community water systems throughout New York State was conducted in 1986 (Meyer et al., 1989). The sampling sites were representative of the major surface source waters in New York. They included sources receiving industrial discharges or known to contain dioxin-contaminated fish, as well as waters in more remote areas. TCDFs were detected in the finished water at the Lockport facility (duplicate samples had concentrations of 2.1 and 2.6 ppq). Except for a trace of OCDF detected at

one location, no other CDDs/CDFs were detected in finished water at any of the other 19 community water systems surveyed. Raw water sampled at the Lockport facility contained concentrations of TCDDs (1.7 ppq) as well as TCDFs to OCDF (18, 27, 85, 210, and 230 ppq, respectively). As can be seen from the data, the CDF congener group concentrations increased with increasing chlorine number.

4.3.2. European Data

CDDs in surface water samples collected from the Eman River in southern Sweden generally increased in concentration from the TCDDs to OCDD; whereas the CDF levels showed very little variation between the congener groups (Rappe et al., 1989b). In general, however, the levels of CDFs were higher than the levels of CDDs. Concentrations of 2,3,7,8-TCDF were 0.022 parts per quadrillion (ppq) in Jarnsjon and 0.026 ppq in Fliseryd. The filtered water, before chlorination and distribution as drinking water, had no detectable tetra-, penta-, or hexa-chlorinated congeners of CDDs or CDFs, but the HpCDDs and OCDD were detected at 120 and 170 ppq, respectively.

4.3.3. Water Summary

Some general observations for CDD and CDF levels are possible from the limited data available from the various water studies above:

- CDDs/CDFs are seldom detected in drinking water at ppq levels or higher.
- Raw water samples generally have higher concentrations of CDDs/CDFs than finished water samples.
- The concentration of CDDs and CDFs in surface water generally increases from the tetra-chlorinated to the octa-chlorinated congener groups.

Based on the above studies, a total of 214 samples were selected as representing background conditions in North America. The mean TEQ level was computed as 0.0056 ppg, assuming that nondetects equal half the detection limit. It should be noted, however, that OCDD and OCDF were the only congeners for which background data were available.

Of the 214 samples analyzed for OCDD, 4 were positive, and 2 out of 22 samples analyzed for OCDF were positive. No appropriate data could be found for Europe.

4.4. CONCENTRATIONS IN SEDIMENT

Tables B-5 through B-7 (Appendix B) contain summaries of data from several of the numerous studies in the published literature regarding concentrations of CDDs, CDFs, and coplanar PCB congeners in sediment. Several of these studies are discussed in the following paragraphs.

4.4.1. North American Data

In sediment samples collected from estuaries adjacent to an industrial site in Newark, New Jersey, where chlorinated phenols had been produced, the level of OCDD was many times higher than that of 2,3,7,8-TCDD (Bopp et al., 1991). The study indicated that there probably is a significant regional source (i.e., combustion and/or use of a common wood preservative, pentachlorophenol) for OCDD depleted in 2,3,7,8-TCDD relative to the local industrial source. A high correlation was found between 2,3,7,8-TCDD and 2,3,7,8-TCDF ($R^2 = 0.87$), which suggests that the industrial site was a major source of 2,3,7,8-TCDF to the natural waters of the study area. An interesting note is that the bottom section (108-111 cm) of one sediment core contained 2,3,7,8-TCDD at a concentration of 21,000 ppt, the highest concentration measured in the study. This value was consistent with deposition of that sample during the mid to later stages of active 2,4,5-T production at the site from the late 1950s to early 1960s. CDD and CDF in Hudson River sediment samples contained primarily the higher chlorinated (Cl_6 to Cl_8) CDD and CDF congeners (Petty et al., 1982). Concentrations of the HpCDDs and OCDD homologues ranged from 5 to 15 ppb, and the OCDD homologue in most instances accounted for more than half of the total CDD residue. Likewise, the HpCDFs and OCDF occurred at the highest levels (ca. 1 ppb).

Surface sediment samples were collected from several estuaries in the United States (Norwood et al., 1989). The sampling sites included Black Rock Harbor in Bridgeport, Connecticut, (an industrialized urban estuary); central Long Island Sound (a

relatively clean reference site); Narragansett Bay, Rhode Island, (where chemical industries may have contributed to the input); New Bedford Harbor, Massachusetts, (a section of which is a National Superfund Site because of PCB contamination); and Eagle Harbor, Washington, (the site of a creosote wood treatment facility). The sediments in New Bedford Harbor were reported to be more heavily contaminated with CDFs, especially with regard to the HxCDF congeners that were greater by a factor of 40 (although individual data points were not presented). In contrast, sediments from Eagle Harbor were practically devoid of CDFs and showed a large increase in the HpCDD and OCDD congeners closer to the treatment facility. Narragansett Bay and Black Rock Harbor were similar in both concentration and distribution of CDDs and CDFs, and Black Rock Harbor contained slightly higher levels of the tetra- to hepta-CDD and CDF congeners. Sediment from Long Island Sound was cleaner and had a distribution of CDFs between that of Narragansett Bay and Black Rock Harbor. Sediment with the least contamination was collected in New Bedford Harbor, up-river from the PCB facilities; the highest OCDD concentration (1400 ppt) was detected in Eagle Harbor.

Sediment samples from Siskiwit Lake, on Isle Royale, Lake Superior, were examined to evaluate the atmospheric input of CDDs and CDFs to the lake (Czuczwa et al., 1984). The water level in Siskiwit Lake is 17 meters higher than that in Lake Superior, and in addition, there are no anthropogenic inputs in the drainage basin of Siskiwit Lake. Consequently, the atmosphere is the only source of anthropogenic chemicals in that lake. OCDD was most predominant, and the HpCDD and HpCDF congeners also were abundant. The study indicated that the considerable decrease in concentration of all CDD and CDF between 6 and 8 cm of the sediment core depth (i.e., sediment believed to have been deposited about 1940).

Surficial sediments collected from Jackfish Bay on the north shore of Lake Superior contained moderate concentrations of the TCDF and OCDD congeners, with trace concentrations of other congeners (Sherman et al., 1990). The concentration of OCDD was similar to that found in the Siskiwit Lake sediment samples. The OCDF and OCDD profile for a sediment core collected from Moberly Bay was similar to the surficial sediment pattern. These congener groups predominated at all depths where detectable

concentrations occurred. In addition, low concentrations of the HpCDD and PeCDF and HpCDF congeners were detected. The concentration profile of the HpCDF congener group showed a relatively high value that dropped abruptly to nondetectable (< 60 ppt) below a depth of 10 cm. This abrupt change corresponded to a section date 1973 that reflects an operational change at the pulp mill.

A survey of surficial harbor sediments collected near a wood preserving plant in Thunder Bay, Ontario, Canada, on the north shore of Lake Superior, found CDDs and CDFs; the highest concentrations of which occurred at stations closest to the plant dock, and lower concentrations at locations further from the source (McKee et al., 1990). No CDDs or CDFs were detected below the surficial layer. TCDD and PeCDD congeners were below analytical detection limits in all samples. However, the concentrations of the HxCDDs to OCDD congeners increased with the degree of chlorination. The maximum concentrations of the HxCDDs to OCDD ranged from 5,700 ppt for the HxCDDs to 980,000 ppt for the OCDD. As with the CDD distribution profile, the HxCDFs to OCDF increased with the degree of chlorination.

Bottom surficial sediments (0-3 cm) were collected from the sedimentation basins of Lake Ontario to assess the levels of the various PCB congeners (Oliver and Niimi, 1988). Concentrations of 2,3',4,4',5-PeCB; 2,3,3',4,4'-PeCB; and 2,3,3',4,4',5-HxCB in the sediment were 15, 10, and 2.1 ppb, respectively. A baseline assessment of CDDs and CDFs was performed on the Elk River, a semi-rural area located about 25 miles northwest of Minneapolis-St. Paul, Minnesota (Reed et al., 1990). Sediment samples were collected from Lake Orono, a reservoir on the Elk River, and from an abandoned gravel pit. Although none of the sediment samples contained 2,3,7,8-TCDD, the gravel pit sediments contained measurable concentrations of TCDFs. Only one Lake Orono sample contained measurable concentrations of 2,3,7,8-TCDF (0.31 ppt) and total TCDF (0.54 ppt). The gravel pit samples also contained HpCDDs to OCDD and PeCDFs to OCDF. Lake Orono samples contained HpCDDs, OCDD, and HpCDF congeners. The HpCDDs ranged from 7.3 ppt in the lake inlet to 110 ppt in the gravel pit and the lake, near the dam. OCDD concentration ranged from 450 ppt in the gravel pit to 600 ppt in the middle of Lake Orono. The sediment profiles reflected combustion source influences.

The Sheboygan River, a Wisconsin tributary to Lake Michigan, is polluted with PCBs from the mouth to about 14 miles upstream (Sonzogni et al., 1991). That portion of the river is a Superfund site as well as one of the Great Lakes "Areas of Concern." Sediment cores were collected at Rochester Park, near the original source of the PCBs, about 14 miles upstream from the mouth. The PCB congeners 2,3',4,4',5-PeCB; 2,3,3',4,4'-PeCB; and 3,3',4,4'-TCB were detected in all samples and ranged from about 5 to 1500 ppb. The remaining coplanar PCB congeners were detected less frequently and ranged from nondetectable to slightly over 100 ppb. The PCB congener 2,3',4,4',5-PeCB appears to be the most common coplanar PCB in environmental samples and was found in the Sheboygan River sediments in the highest weight percent. The eight toxic PCBs detected in this study were present in relatively low concentrations compared to total PCBs or other more abundant congeners.

Sediments collected from Waukegan Harbor in Lake Michigan contained the coplanar PCB congeners 3,3',4,4'-TCB and 2,3,3',4,4'-PeCB (Huckins et al., 1988). The percentage of 3,3',4,4'-TCB in the samples averaged (0.16 percent ± 0.15) varied by 1.4 orders of magnitude, with concentrations ranging from 13 to 27,500 ppb. The percentage of 2,3,3',4,4'-PeCB averaged 0.66 percent ± 0.37, with concentrations ranging from 102 to 131,000 ppb. In another Lake Michigan study, sediment samples collected from Green Bay contained concentrations of all 11 coplanar PCB congeners (Smith et al., 1990). The dominant congeners were 2,3,4,4',5-PeCB and 2,3,3',4,4'-PeCB with concentrations of 11 and 5.8 ppb, respectively.

4.4.2. European Data

Sediment samples from the vicinity of a magnesium production plant in Norway were analyzed for CDDs and CDFs (Oehme et al., 1989). The concentration distribution of CDD and CDF congeners was rather homogeneous except for a slight decrease at a sampling station further downstream of the plant. However, the deeper sediments (4-6 and 11-13 cm depth) at that site had somewhat higher levels. Another sampling station even further downstream had concentrations that were a factor of 4 to 10 lower, thereby indicating substantial transport of CDDs and CDFs. The TCDF congener profiles were the

same as those for magnesium production. In addition, the PeCDF congener profiles were very similar to those found in the wastewater.

Trapped sediments from the archipelago of Stockholm, Sweden, displayed CDD and CDF congener distribution patterns that were very similar to those exhibited in total air and air particulates (Rappe and Kjeller, 1987). The HpCDDs, OCDD, and HpCDF were the dominant congener groups in the sediment.

Bottom surface sediment samples collected from the Baltic Sea showed interesting CDD and CDF distribution patterns (Rappe et al.,1989a). The background samples, one between the Swedish and Soviet coasts and the other between the Swedish and Finnish coasts, contained similar levels and distribution profiles. The study indicated that the pattern of the TCDF congeners at these sites was typical of the "incineration pattern" (i.e., patterns resulting from MSW incineration, car exhausts, steel mills, etc.) which also had been found in samples of air and air particulates. However, sediment samples collected at a distance of 4 to 30 km from a pulp mill revealed a congener distribution pattern typical of bleaching mills. The TCDFs found in the sediment 4 km from the pulp mill contained only two major congeners. The sediment collected 30 km from the mill displayed the same pattern.

Surface sediments collected from 18 lake areas in central Finland were analyzed for CDDs, CDFs, and PCBs. Although 2,3,7,8-TCDD was not detected in any samples, two other TCDD congeners that are common and abundant in pulp mill effluents were detected. In addition, the HxCDD to OCDD congener groups as well as the HpCDF and OCDF congener groups not normally linked to pulp mills, also were detected. The study suggested that these may have resulted from combustion operations in the more densely populated and industrialized areas in south Finland. Coplanar PCBs were detected at low background levels. The most toxic PCB congener, 3,3',4,4',5-PeCB (IUPAC No. 126), was found only in one area located nearest to a PCB leakage point. The concentration of PCB 126 at that site was 110 ppt.

Evaluation of sediments in Hamburg Harbor in Germany revealed high concentrations of the TCDDs through OCDD (mean concentrations of 564, 1112, 2744, 4040, and 7560 ppt, respectively) and the TCDFs through OCDF (mean concentrations of

526, 2980, 4106, 2358, and 2712 ppt) (Gotz et al., 1990). The average concentration of 2,3,7,8-TCDD was 375.3 ppt. The high concentrations of 2,3,7,8-TCDD, especially in the Moorfleeter Canal and the Auserer Vering Canal, were attributed to discharges from an organochlorine pesticide manufacturing plant. The patterns of 2,3,7,8-TCDD and the other HpCDD congeners are characteristic of the patterns resulting from the production of 2,4,5-T and 2,4,6-trichlorophenol. In addition, the pattern of the HpCDF congeners can be linked to emissions from thermal processes employed by chemical industries in the production of chlorinated organic chemicals. The high concentrations of hepta- and octa-CDDs/CDFs may also be the result of other industrial combustion processes in the Hamburg area.

4.4.3. Sediment Summary

Some general observations for CDD and CDF levels are possible from the data presented in the various sediment studies above:

- The CDD and CDF congener distribution patterns in sediment generally follow those exhibited by the contaminant source.
- The concentration of hexa- to octa-chlorinated CDD and CDF congeners in sediment is usually the result of industrial processes and generally increases with the degree of chlorination, but decreases uniformly with distance from the source.

Based on the above studies, seven samples were selected as representing background conditions in the United States. The mean TEQ level was computed as 3.9 ppt assuming that nondetects equal half the detection limit. Similarly, 20 background samples were selected from the European data with a mean of 34.9.

4.5. CONCENTRATIONS IN FISH AND SHELLFISH

Tables B-8 through B-10 (Appendix B) contain summaries of data from the numerous studies in the published literature regarding concentrations of CDDs, CDFs, and

coplanar PCB congeners in fish and shellfish. PCB congener data were found only for North American species. It should be noted that some studies reported fish concentrations on a whole weight basis and others reported concentrations for fish fillets. Whole weight concentrations were converted to fillet concentrations assuming that the fillet contained one-half the concentration of the whole fish (USEPA 1990; Branson et al. 1985). This was necessary for estimating human exposures because it is assumed that fish fillets, and not whole fish, are ingested by humans.

4.5.1. North American Data

A large quantity of fish data were collected as part of EPA's National Study of Chemical Residues of Fish (NSCRF), more commonly referred to as the National Bioaccumulation Study, during the period of 1986 to 1989 (U.S. EPA, 1992). Based on these data, several summaries were prepared and are presented here. Tables B-8 and B-9 include the dioxin and furan data collected as part of the National Bioaccumulation Study. Samples were collected from a wide variety of sites across the United States, including 314 sites thought to be influenced by point or nonpoint sources and 35 sites identified as relatively free of influence from point and nonpoint sources. This latter group of sites can be characterized as background per the definition used in this document. Background data are presented in Table 4-1. Table B-10 includes similar data for the various PCB congener groups from 362 National Bioaccumulation Study sites. Because the specific PCB congeners could not be identified, it is not known what percentage of these concentrations represent the PCBs identified as dioxin-like. Twenty of these sites were identified as background sites. The total PCB, all 209 congeners, mean concentration for these background sites was 46,900 ppt. Because the dioxin-like PCBs consist of only 11 of the 209 possible PCB congeners, it may be that they are a small percentage of the total. However, only congener specific analysis can ultimately confirm this. As discussed at the end of this section (in 4.5.3), this study was selected as the best basis for estimating background fish levels in the United States.

Samples of striped bass, blue crabs, and lobsters collected from Newark Bay and the New York Bight all contained high levels (up to 6,200 ppt) of 2,3,7,8-chlorine

Table 4-1. Background Data from the National Bioaccumulation Study

Congener	No. of Background Sites	Concentration Range[a] (pg/g)	Mean Conc.[a] (pg/g)	Standard Deviation[a] (pg/g)	Median Conc.[a] (pg/g)
2,3,7,8-TCDD	34	0.06 - 2.26	0.56	0.38	0.50
2,3,7,8-TCDF	34	0.10 - 13.73	1.61	2.51	0.90
1,2,3,7,8-PeCDD	33	0.15 - 2.67	0.77	0.54	0.54
1,2,3,7,8-PeCDF	34	0.10 - 1.90	0.43	0.31	0.39
2,3,4,7,8-PeCDF	34	0.10 - 1.39	0.50	0.36	0.42
Tot HxCDDs	30	ND - 3.57	0.39	0.8	ND
Tot HxCDFs	29	ND - 2.59	0.22	0.66	ND

Source: U.S. EPA (1992)

[a] Concentrations are picograms per gram (pg/g) by wet weight. The mean, median, and standard deviation were calculated using one-half the detection limit for samples that were below the detection limit. In cases where multiple samples were analyzed per site, the value used represents the highest concentration.

Note: ND = non-detect.

substituted tetra- and penta-CDDs and CDFs (Rappe et al., 1991). The levels of 2,3,7,8-TCDD were higher than any other New Jersey samples, and the highest sample in this study may be the highest level of 2,3,7,8-TCDD ever reported for aquatic animals. The crustaceans resembled one another in congener pattern. Specifically, they all contained both a large number and large amounts of CDD and CDF congeners in addition to the 2,3,7,8-chlorine substituted compounds. The striped bass samples, on the other hand, contained primarily the 2,3,7,8-chlorine substituted congeners.

Carp, catfish, striped bass, large mouth bass, and lake trout were collected from sites in the Hudson River and the Great Lakes Basin that were contaminated with industrial chemicals or contained known or suspected levels of PCBs (Gardner and White, 1990). The congener 2,3,7,8-TCDF was detected in 12 fish at levels that ranged from 3 to 93 ppt. A 2,3,7,8-chlorine substituted PeCDF was detected in 14 fish at levels ranging from 4 to 113 ppt. An interesting observation in this study was that 2,4,6-chlorine substituted CDFs were detected in four fish samples, suggesting that those fish may have been exposed to chlorinated phenols. The study indicated that the 2,4,6-chlorine substituted CDFs occurred in the fish at levels similar to those of the 2,3,7,8-chlorine substituted CDFs, but with less frequency.

Samples of lake trout or walleye collected from each of the Great Lakes and Lake St. Clair were analyzed for CDDs and CDFs (De Vault et al., 1989). CDF and CDD concentrations in lake trout were substantially different for each lake and between sites in Lake Michigan, probably reflecting differences in types and amounts of loadings to the lakes. In all of the sampling sites except Lake Ontario, 2,3,7,8-TCDF was the dominant CDF congener in lake trout and ranged from 14.8 ppt in Lake Superior to 42.3 ppt in Lake Michigan. In Lake Ontario, the dominant congener in lake trout was a 2,3,7,8-chlorine substituted PeCDF. The distribution of CDF congeners in the Lake Erie walleye was very similar to that of the lake trout from Lake Superior. With regard to CDDs, the concentrations of 2,3,7,8-TCDD ranged from 1 ppt in Lake Superior to 48.9 ppt in Lake Ontario. With the exception of Lake Ontario, the dominant CDD congener was a 2,3,7,8-chlorine substituted PeCDD. A 2,3,7,8-chlorine substituted HxCDD also contributed significantly to the total CDD concentrations. As with CDFs, the distribution

of CDD congeners in the Lake Erie walleye was very similar to that of the lake trout from Lake Superior.

In another study, CDDs and CDFs were measured in four species of salmonids (lake trout, coho salmon, rainbow trout, and brown trout) collected from Lake Ontario (Niimi and Oliver, 1989a). Levels of 2,3,7,8-TCDD in whole fish ranged from 6 to 20 ppt, and the HxCDD congener group was most dominant in all fish. High levels of OCDD also were detected in lake trout and coho salmon, but not in rainbow trout or brown trout. Although the total CDF levels were about 25 percent lower than the total CDD concentrations, the levels of 2,3,7,8-TCDF (which was the dominant component of the TCDF congener group) were the same range as 2,3,7,8-TCDD (6 to 20 ppt). However, the study suggested that, although collection sites can influence chemical levels and congener composition, comparisons of chemical levels and congener frequencies may not be suitable because of differences resulting from localized factors. The study also indicated that the importance of the various CDD and CDF congeners can differ with location (i.e., the same species of fish collected at different locations in a study area may reveal that the most common congener is different at each site).

Travis and Hattemer-Frey (1991) evaluated data generated as part of the National Dioxin Study regarding 2,3,7,8-TCDD concentrations in fish. The fish were collected from 304 urban sites in the vicinity of population centers or areas with known commercial fishing activity, including sites from the Great Lakes Region. Data from that study indicated that concentrations of 2,3,7,8-TCDD in whole fish from urban sites ranged from nondetectable to 85 ppt. In addition, only 29 percent of the fillets from urban sites had detectable levels of 2,3,7,8-TCDD, with a geometric mean concentration of 0.3 ppt. Whole fish samples from the Great Lakes Region had higher 2,3,7,8-TCDD levels than fish from urban areas (e.g., 80 percent vs 35 percent detectable levels). In the Great Lakes Region, 2,3,7,8-TCDD concentrations in whole fish samples ranged from nondetectable to 24 ppt, with a geometric mean of 3.8 ppt. These levels were 10 times higher than the concentration in whole fish from urban areas. Likewise, the mean concentration of 2,3,7,8-TCDD in Great Lakes Region fish fillets (2.3 ppt) was about seven times higher than the levels in the fillets from urban areas (0.3 ppt). As with the whole fish samples,

fish fillet samples from the Great Lakes Region had higher 2,3,7,8-TCDD levels than fillets from background urban areas (e.g., 67 percent vs 29 percent detectable levels). Comparable levels of 2,3,7,8-TCDD were detected in whole bottom feeders and predators from the Great Lakes Region.

Samples from all trophic levels in the Lake Ontario ecosystem were analyzed for PCB congeners (Oliver and Niimi, 1988). Analysis revealed that the PCB concentration increased from water to lower organisms to small fish to salmonids, demonstrating the classical biomagnification process. In addition, the chlorine content of the PCBs increased at the higher trophic levels. PCBs with the highest chlorine content (57 percent) were found in sculpin, small bottom-living fish that feed on benthic invertebrates. The TrCBs and TCBs comprised a much higher percentage of the PCBs in the lower trophic levels than in salmonids and small fish. The percentage of PeCBs and OCPB in all samples was fairly uniform, but the HxCBs and HpCBs comprised a much larger fraction of the PCBs in the small fish and salmonids than in the lower trophic levels.

A study regarding the distribution of PCBs in Lake Ontario salmonids (brown trout, lake trout, rainbow trout, and coho salmon) showed that the PeCBs and HxCBs were dominant in all species (Niimi and Oliver, 1989b). The 10 most common PCB congeners represented about 52 percent of the total content and did not appear to be influenced by species or total concentration. The homologues observed averaged approximately 56 percent chlorine by weight in whole fish and muscle. The analysis of the chlorine content suggested that the more persistent congeners tend to behave as a homogeneous mixture instead of as individual congeners.

4.5.2. European Data

Evaluation of fish in the Baltic Sea (Gulf of Bothnia) and northern Atlantic Ocean in the vicinity of Sweden revealed that concentrations of CDDs and CDFs in herring from the Atlantic Ocean were lower than those in the Gulf of Bothnia (Rappe et al., 1989b). Detectable levels of 2,3,7,8-TCDD in salmon were found in both wild homing (4.6 to 19 ppt) and hatchery-reared (0.2 to 0.3 ppt) varieties in the Gulf of Bothnia. In addition, concentrations of the same representative congeners of the Cl_5 to Cl_8 CDD and CDF

congener groups found in herring were found in both varieties of salmon. Levels of those congeners in the wild salmon, however, were five to ten times higher than the herring levels, while the levels in the hatched salmon essentially were the same as in the herring samples. Perch collected at a distance of 1-6 km from a pulp mill in the southern part of the Gulf of Bothnia contained 2,3,7,8-TCDD and 2,3,7,8-TCDF; the levels were higher in the samples collected closer to the pulp mill. These two compounds have been identified in bleaching effluents from pulp mills as well as in bleached pulp. Arctic char collected from Lake Vattern, a popular fishing lake in southern Sweden, contained levels of 2,3,7,8-TCDD (6.5 to 25 ppt), 2,3,7,8-TCDF (21 to 75 ppt), and representative congeners of the PeCDD and PeCDF homologues. There was a good correlation between the weight of the fish and the levels of CDDs and CDFs. The main general pollution sources of the long, deep, narrow lake are two pulp mills.

Fish (cod, haddock, pole flounder, plaice, flounder, and eel), mussels, and edible shrimps from a fjord area contaminated by wastewater from a magnesium factory in Norway were analyzed for CDDs and CDFs (Oehme et al., 1989). Certain magnesium production processes can result in the formation of substantial amounts of CDDs and CDFs as byproducts. The congener pattern of Cl_4 and Cl_5 CDDs and CDFs released in wastewater during the magnesium production process is very characteristic and is dominated by congeners with chlorine in the positions 1,2,3,7 and/or 8. Fish and shellfish differ in their ability to bioconcentrate CDD and CDF congeners. For example, fish generally only concentrate the most toxic 2,3,7,8-substituted congeners, whereas shellfish can usually concentrate most of the congeners. Nearly all congeners were present in the shrimp and mussel samples. Although these organisms displayed the very characteristic PeCDF congener pattern of the magnesium production process, some deviations were found in the TCDF congener distribution within those species. For fish, the concentrations of CDDs and CDFs are dependent on the exposure level, fat content, living habit, and the species degree of movement. The highest CDD and CDF levels were found in comparatively high fat-content bottom fish collected close to the source. Cod and haddock, lower fat-content nonstationary fish, had much lower concentrations, even in the vicinity of the magnesium production factory. An interesting note is that the main

stream of the fjord follows the west coast; subsequently, cod and eel samples collected along the west coast of the fjord had considerably higher levels of CDDs and CDFs than those collected from the eastern fjord entrance. Similarly, the level of 2,3,7,8-TCDD in mussels decreased by one order of magnitude from the vicinity of the magnesium production factory to the outer region of the fjord system.

Brown trout, grayling, barbel, carp, and chub collected in the Neckar River in southwest Germany contained much higher levels of 2,3,7,8-TCDF than in eels collected from the same river and the Rhine River (Frommberger, 1991). In addition, eels from both rivers showed very similar patterns for CDD and CDF congener distribution, whereas the patterns of CDD and CDF distribution generally showed some degree of difference among the other fish collected from the Neckar River. Perch and bream collected from various locations in the vicinity of Hamburg Harbor, however, showed similar patterns in the distribution of the Cl_4 to Cl_8 CDD and CDF congener groups (Gotz et al., 1990). In general, the levels of CDFs were higher than the level of CDDs in these fish, especially with regard to the TCDFs to HxCDFs. Pooled samples of eels collected at six different localities in the Netherlands contained low levels of CDDs and CDFs, the major congeners of which were 2,3,7,8-chlorine substituted (Van den Berg et al., 1987). The concentrations of the various congeners identified in the eel samples ranged from 0.1 to 9.1 ppt. The sample with the highest concentration of 2,3,7,8-TCDD (9.1 ppt) was collected from Broekervaart in a location that was not far from a chemical waste dump that contained high concentrations of the same congener.

4.5.3. Fish Summary

Some general observations for CDD and CDF levels are possible from the data presented in the various fish and shellfish studies above:

- Fish and shellfish differ in their ability to bioconcentrate CDD and CDF congeners. Fish generally concentrate the most toxic 2,3,7,8-substituted congeners, but shellfish can usually concentrate most congeners.

- For fish, the concentrations of CDDs and CDFs are dependent on the exposure level, fat content, living habits, and the degree of movement of the species. Comparatively high fat-content bottom fish collected close to the contaminant source generally have the highest CDD/CDF levels, whereas lower fat content, nonstationary fish have much lower concentrations, even in the vicinity of the contaminant source.
- The National Dioxin Study indicated that the levels of 2,3,7,8-TCDD in fish from the Great Lakes Region were higher than those from urban areas. Comparable levels were detected in whole bottom feeders and predators from the Great Lakes Region.
- With regard to PCBs, concentrations increase from water to lower organisms to small fish to salmonids, and the chlorine content of the PCBs increase at the higher trophic levels.

The background fish data collected as part of EPA's National Bioaccumulation Study (EPA, 1992) were selected as the best basis for identifying background levels in U.S. fish. Sixty fish samples were collected from fresh and estuarine water at a total of 34 sites where no obvious industrial sources were present. The average TEQ (assuming zero for the nondetects) was 0.59 ppt, and 1.2 ppt (assuming half the detection limit for the nondetects). In the original study, some of the samples were analyzed on a whole body basis and others on a fillet basis. However, for purposes of this document, whole body data were converted to a fillet basis. All concentrations were expressed on a wet weight basis. This information is based on the report and clarifications provided via a personal communication from Annette Huber, Office of Water, to John Schaum, Office of Research and Development, May 17, 1993. Several points should be considered in using these estimates to assess human exposure:

- The National Bioaccumulation Study data were derived from fresh and estuarine water fish and, therefore, are not representative of open ocean fish. Some types of open ocean fish such as tuna and sword fish are

commonly eaten. The cod and haddock data from Schecter et al. (1993) could be representative of these species. (See discussion in Section 4.6.2.) These data showed a range of 0.023 to 0.13 ppt. Presumably, the contaminant levels in open ocean fish are lower than fresh water and estuarine fish because they live in waters farther from dioxin sources.

- Whole fish contaminant levels are normally twice as high as fillets, which is generally considered the edible portion. However, some small fish and shell fish, such as clams, are typically eaten whole.

- These "background" samples may not be representative of what many individuals consume. EPA (1992) found an average of 11 ppt of TEQ across all 314 locations sampled. Even though these other locations were near industrial point sources, recreational or subsistence fishermen from local populations may consume fish from these waters.

- Market basket surveys would probably provide the best information on dioxin levels in fish commonly consumed by the general population. Data of this type were provided by Schecter et al. (1993). As discussed in Section 4.6.2., this study analyzed five fish collected from a supermarket and found an average of 0.05 ppt of TEQ. These data may mean that fish exposure levels are lower than the value selected here as representative of background levels (i.e., 1.2 ppt). However, only a limited number of samples were analyzed. Also the fish samples represent ocean species, whereas the National Bioaccumulation Study sampled freshwater and estuarine fish.

4.6. CONCENTRATIONS IN FOOD PRODUCTS

Dietary intake is generally recognized as the primary source of human exposure to CDD/Fs (Rappe, 1992). Several studies have estimated that over 90 percent of the average daily exposure to CDD/Fs are derived from foods (Rappe, 1992; Henry et al.,

1992; Fürst et al., 1991). CDD/Fs in fatty foods such as dairy, fish, and meat products are believed to be the major contributors to dietary exposures (Rappe, 1992; Henry et al., 1992). Travis and Hattemer-Frey (1991), using a fugacity model, estimated that the food chain, especially meat and dairy products, accounts for 99 percent of human exposure to 2,3,7,8-TCDD.

Analysis of trace levels of CDD and CDF congeners in food has in the past been hindered by lack of sensitive analytical detection methods, extraction difficulties from the high-lipid content food products in which these chemicals are most often found, and the presence of other potentially interfering organochlorine compounds. As the analytical difficulties associated with detecting CDD and CDF congeners at ppt levels or lower are overcome (Firestone, 1991), more food data should be generated.

Tables B-11 and B-12 (Appendix B) contain summaries of data from the recent published literature regarding concentrations of CDDs and CDFs in food products. Most of the selected studies investigated "background" levels of CDDs and CDFs rather than studies targeted at areas of known contamination. Table B-13 contains a summary of PCB congener concentrations in food products.

The studies summarized in Tables B-11 and B-12 primarily examined CDD and CDF levels in products of animal origin (i.e., fish, meat, eggs, and dairy products). Because of their lipophilic nature, CDDs and CDFs are expected to accumulate in these food groups. The data in the tables indicate that CDDs and CDFs are found at levels ranging from the intermediate ppq up to the low ppt range. As expected, the highest levels reported are those measured in foods with high animal fat content. The highest reported congener concentrations are for the HpCDDs and OCDD. In general, for the less-chlorinated congener groups (i.e., Cl_4 - Cl_6), the CDF levels measured were larger than the CDD levels but were still within an order of magnitude. The situation is reversed for the Cl_7 and Cl_8 congener groups.

4.6.1. Migration of CDD/CDF from Paper Packaging Into Food

In the past, low levels of CDDs and CDFs have been detected in bleached paper. (See discussion in Chapter 3.) Because bleached paper is sometimes used for food

packaging, concern has been expressed that CDD/Fs may migrate from the paper into the food.

Using refined and highly sensitive analytical methods, LaFleur et al. (1990) observed the migration of 2,3,7,8-TCDD; 2,3,7,8-TCDF; and 1,2,7,8-TCDF from bleached paper milk cartons into whole milk. After 12 days of exposure, 6.7 percent of the 2,3,7,8-TCDD; 18 percent of the 2,3,7,8-TCDF; and 13 percent of the 1,2,7,8-TCDF in the milk carton leached into the milk. The concentrations of the three congeners in milk were 8.5, 110, and 49 pg/kg for 2,3,7,8-TCDD; 2,3,7,8-TCDF; and 1,2,7,8-TCDF, respectively. [Note: These data are not reported in Appendix B; only data for raw milk are reported.]

The study results reported by LaFleur et al. (1990) were performed by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) at the request of the U.S. Food and Drug Administration (FDA) as part of a cooperative Federal agency effort to assess the risks posed by dioxin contamination of paper products (i.e., the Federal Interagency Working Group on Dioxin-in-Paper). In addition to assessing the migration of CDDs and CDFs from milk cartons, studies were also conducted to assess the extent of CDD/CDF migration into food from coffee filters, cream cartons, orange juice cartons, paper cups for hot beverages, paper cups for soup, paper plates for hot foods, dual ovenable trays, and microwave popcorn bags. Migration of CDD/Fs from the paper into food was observed in all studies.

The FDA report presented data on direct measurements in these paper articles, showing TCDD and TCDF levels in the 1 - 13 ppt range. These levels were similar to the levels measured in bleached wood pulp which averaged about 8 ppt at the time of the study. As discussed in Section 3.2, the paper industry has made process changes that they expect have generally reduced dioxin levels in bleached paper pulp to less than 2 ppt of TEQ. Similar or lower levels could be expected in final paper products. NCASI reports that essentially no detectable migration of dioxin to milk occurs from cartons at these levels.

The results of these migration studies and an assessment of the risks to the general population posed by migration from paper are addressed in detail in U.S. EPA (1990a).

The CDD/CDF levels currently found in food due to any leaching of dioxin-like compounds from paperboard containers are expected to be significantly lower than those reported in U.S. EPA (1990a) because of process changes implemented by the pulp and paper industry to reduce formation of CDDs and CDFs.

4.6.2. U.S. Food

The published data on measured levels of CDDs, CDFs, and dioxin-like compounds in U.S. food products have generally come from studies of a specific food product(s) in a specific location(s) rather than from large survey studies designed to allow estimation of daily intake of the chemicals for a population. For example, CDD/Fs are not routinely monitored in the U.S. Food and Drug Administration's (FDA) Surveillance Monitoring Program for domestic and imported foods (conversation between Dr. S. Page, FDA, and G. Huse, Versar, Inc., February 8, 1993) nor are they routinely monitored by the U.S. Department of Agriculture (USDA) in the National Meat and Poultry Residue Monitoring Program (conversation between Dr. E. A. Brown, USDA-FSIS, and G. Schweer, Versar, Inc., February 8, 1993).

However, USDA has developed some site-specific, though dated (late 1970s), CDD monitoring data. These efforts were in response to a decline in general health noted by inspectors in several cattle herds in Michigan. Wood products in the local barns and other cattle holding premises, presumed to be treated with pentachlorophenol (PCP), were suspected as the cause of this health decline (Buttrill et al., no date; Tiernan et al., 1978). PCP was suspected to contain trace CDD and CDF levels as manufacturing contaminants at that time. In response to this incident, two national investigations were performed by USDA. The first study involved the analysis of peritoneal adipose and liver samples collected from beef cattle in 23 States (Tiernan et al., 1978), while the second study involved the analysis of adipose tissue samples (body region not specified) collected from dairy cattle in 30 States--neither study specified the cattle breeds for any sample. HxCDD, HpCDD, and OCDD were screened for in the analyses of samples from each study. In the beef cattle study (Tiernan et al., 1978), 220 samples were analyzed: 189 peritoneal adipose samples and 31 liver samples. No residues were detected in any liver samples. A

total of 19 (i.e., 10 percent) of the 189 adipose samples were found to positively contain HxCDD, HpCDD, or OCDD levels >0.10 ppb, while 56 (i.e., 30 percent) contained levels <0.10 ppb that were detectable based on the signal-to-noise ratio of the analytical instrumentation. OCDD accounted for the majority of the samples that positively contained CDDs (i.e., 17 or 9.0 percent) while only 3 samples contained HxCDD and 2 samples contained HpCDD residues, respectively. A total of 358 adipose samples were analyzed in the dairy cattle study (Buttrill et al., no date). Nine samples (i.e., 2.5 percent) positively contained CDD levels >0.19 ppb or the "level of reliable measurement", while another 30 samples (i.e., 8.4 percent) contained CDD levels that were identifiable yet below the "level of reliable measurement" (i.e., not positively identified due to low concentration levels). As with the beef cattle study results, OCDD accounted for the majority (eight) of positive samples. HpCDD was identified in only a single sample that also contained OCDD. HxCDD was identified as well in only a single sample. The data from the USDA studies are not useful for estimating CDD/F exposure for two reasons. First, the samples were analyzed for only 3 of the 17 CDD/F congeners with dioxin-like toxicity, and these were reported on a homolog basis rather than a congener-specific basis. Second, the limit of detection was at or above 0.1 ppb or 100 ppt. Background levels for individual congeners appear to be much less than 100 ppt. For example, the highest congener levels in beef fat analyzed by Fürst et al. (1990) were 5.4 ppt for OCDD.

FDA has also conducted some limited analyses for the higher-chlorinated dioxins in market basket samples collected under FDA's Total Diet Program (Firestone et al. 1986). Food samples found to contain PCP residues >0.05 μg/g were analyzed for 1,2,3,4,6,7,8-HpCDD and OCDD. Also, selected samples of ground beef, chicken, pork, and eggs from the market basket survey were analyzed for these dioxin congeners, regardless of the results of PCP residue analysis. A total of 16 ground beef samples, 18 pork samples, 16 chicken samples, and 17 eggs samples with no PCP contamination were collected between 1979 and 1984 at various locations throughout the United States and analyzed for 1,2,3,4,6,7,8-HpCDD and OCDD. No dioxin residues were detected in any of the ground beef or egg samples. OCDD was observed at detectable concentrations in only 2 of the 18 pork samples (27 ppt 53 ppt) and 2 of the 16 chicken samples (29 ppt, 76 ppt).

One chicken sample with PCP residues >0.05 μg/g had detectable residues of both 1,2,3,4,6,7,8-HpCDD (28 ppt) and OCDD (252 ppt). Egg samples from Houston, Texas and Mesa, Arizona with PCP residues >0.05 μg/g had detectable 1,2,3,4,6,7,8-HpCDD levels ranging from 21 ppt to 588 ppt, and OCDD levels ranging 80 ppt to 1610 ppt. These levels were attributed to local PCP contamination (Firestone et al., 1986). Milk samples contaminated with PCP at levels ranging from 0.01 μg/g to 0.05 μg/g PCP contained no detectable dioxins. It should be noted that these food residue data were not used in this assessment of dioxin exposures in the United States because the reported limits of detection (10 to 40 ppt) for the FDA analyses were considerably higher than the levels of dioxins observed in foods from more recent studies. Also, the study only analyzed for residues of 2 of the 17 toxic CDD/CDF congeners. Finally, the study focussed on samples with PCP contamination and, therefore, was not generally representative of background exposures.

The primary sources of information on background levels of CDD/Fs in U.S. foods are studies conducted by the California Air Resources Board (CARB), the results of background analysis from the NCASI study (Stanley and Bauer, 1989; LaFleur et al., 1990) and Schecter et al. (1993). Each of these three studies is summarized below.

CARB collected multiple samples of seven types of foods from commercial food sources in two urban areas of California (Stanley and Bauer, 1989). Foods were collected randomly, but an emphasis was placed on food stuffs of California origin (Stanley and Bauer, 1989). The types of food stuffs included saltwater fish, freshwater fish, beef, chicken, pork, milk, and eggs. A total of 210 samples were collected in Los Angeles (30 individual samples of each of the 7 types of foods), and 140 samples were collected in San Francisco (20 individual samples of each of the 7 types of foods). Food items were composited before chemical analysis to obtain a sample that was representative of average levels of PCDDs and PCDFs in the food stuffs, increase the probability of detection, and reduce the cost of chemical analysis. Samples were composited separately for each type of food stuff, within each geographical area. Each composite sample contained 6 to 10 individual food samples, and 5 to 8 composite samples were analyzed for each food type. Beef (ground beef), pork (bacon), and chicken samples were analyzed on a lipid weight

basis, but were subsequently converted to a wet weight basis, for the purposes of this report, by multiplying the lipid weight concentration of CDD/CDFs by the fraction of fat contained in the food product of interest. Milk and fish samples were also analyzed on a lipid weight basis. Egg samples were analyzed for CDD/CDFs on a wet weight basis. The CARB data are summarized in Table 4-2.

The NCASI study (as described by LaFleur et al., 1990; and Henry et al., 1992) collected random food samples directly from the shelves of grocery stores located in the southern, midwestern and northwestern regions of the United States. The samples were analyzed for 2,3,7,8-TCDD and 2,3,7,8-TCDF. These data are summarized in Table 4-3.

Schecter et al. (1993) conducted a complete congener analyses of 18 food samples collected directly from a supermarket in Binghamton, New York in early 1990. The samples included five fish, three types of beef (ground beef, beef sirloin tip, and beef rib steak), one chicken drumstick, one porkchop, one lamb, one ham, one bologna, one heavy cream, and four types of cheese. The following ranges of TEQ levels on a whole weight basis were found: fish: 0.01 - 0.13 ppt; meat: 0.03 - 1.5 ppt; and dairy products: 0.04 - 0.7 ppt. These data are summarized in Table 4-4.

Beef and Pork

Background TEQ concentrations of CDD/Fs in beef/veal and pork were estimated using data from eight CARB samples (Stanley and Bauer, 1989), three NCASI background samples (LaFleur et al., 1990), and three samples from Schecter et al. (1993). The CARB and Schecter et al. samples were analyzed for 16 2,3,7,8-substituted CDD/F congeners; the NCASI samples were analyzed for 2,3,7,8-TCDD and 2,3,7,8-TCDF only. At least one congener was detected in 13 of the 14 composite beef samples. One sample had no detectable congeners. The congeners most frequently detected in beef/veal were 1,2,3,4,6,7,8-HpCDD and OCDD, and only one congener was not detected in any of the samples. For the purposes of this report, the total whole weight TEQ for beef was calculated by assuming that the lipid content of beef was 19 percent and by using one-half the detection limits to represent the concentration of nondetectable CDD/F congeners in the samples. Using this methodology, the total background TEQ was estimated to be 0.48

Table 4-2. Summary of Dioxin/Furan Data Collected in the California State Air Resources Board Study

Congener	Beef		Pork		Chicken		Eggs	
	Fraction of composite samples that were positive	Concentration range of positive samples (pg/g)[a,b]	Fraction of composite samples that were positive	Concentration range of positive samples (pg/g)[a,b]	Fraction of composite samples that were positive	Concentration range of positive samples (pg/g)[a,b]	Fraction of composite samples that were positive	Concentration range of positive samples (pg/g)[c]
2,3,7,8-TCDD	0/8	-	0/8	-	3/8	0.31-1.67	0/8	-
1,2,3,7,8-PeCDD	0/8	-	0/8	-	0/8	-	0/8	-
1,2,3,4,7,8/1,2,3,6,7,8-HxCDD	3/8	0.72-3.96	2/8	2.83-3.50	1/8	2.29	0/8	-
1,2,3,7,8,9-HxCDD	0/8	-	0/8	-	2/8	2.14-4.30	0/8	-
1,2,3,4,6,7,8-HpCDD	7/8	3.53-8.95	8/8	3.04-45.50	7/8	1.10-35.20	0/8	-
OCDD	7/8	7.75-11.90	8/8	13.70-254.0	7/8	2.61-96.20	1/8	1.30
2,3,7,8-TCDF	3/8	0.63-1.56	0/8	-	1/8	0.67	1/8	0.011
1,2,3,7,8-PeCDF	0/8	-	0/8	-	0/8	-	0/8	-
2,3,4,7,8-PeCDF	0/8	-	0/8	-	0/8	-	0/8	-
1,2,3,4,7,8-HxCDF	0/8	-	0/8	-	0/8	-	0/8	-
1,2,3,6,7,8-HxCDF	0/8	-	0/8	-	0/8	-	0/8	-
1,2,3,7,8,9-HxCDF	0/8	-	0/8	-	0/8	-	0/8	-
2,3,4,6,7,8-HxCDF	0/8	-	0/8	-	0/8	-	0/8	-
1,2,3,4,6,7,8-HpCDF	4/8	0.48-1.15	7/8	1.57-10.60	6/8	1.01-24.60	1/8	0.065
1,2,3,4,7,8,9-HpCDF	0/8	-	0/8	-	0/8	-	0/8	-
OCDF	0/8	-	5/8	1.24-9.36	2/8	3.79-26.00	0/8	-

[a] Concentration reported on a lipid weight basis.

[b] For some of the concentrations reported, the ratio of characteristic ions were outside the qualitative identification data quality objectives.

[c] Concentration reported on a whole weight basis.

Source: Stanley and Bauer (1989).

Table 4-3. Summary of U.S. Food Data from NCASI Study

Food	Number of Samples	2,3,7,8-TCDD Level[a] (Food basis, pg/kg)	2,3,7,8-TCDD Level[a] (Lipid basis, pg/kg)	2,3,7,8-TCDF Level[a] (Food basis, pg/kg)	2,3,7,8-TCDF Level[a] (Lipid basis, pg/kg)
Milk	1	1.8	48	ND	ND
Half & Half	2	7.2; 8.7	55; 67	NR	NR
Ground beef	3	17; 18; 62	71; 141; 352	ND(3.8); ND(4.8); 5.2	ND(16); ND(27); 41
Corned beef hash	14	7.2-20	54-144	ND(5.9); ND(17); 4.7-12	ND(39); ND(120); 33-103
Beef hot dogs	3	12; 15; 37	44; 56; 128	ND(7.7); 11; 11	ND(28); 38; 41
Ground pork	3	ND(5.8); ND(6.5); ND(6.5)	ND(18); ND(22); ND(27)	13; 13; 20	45; 53; 62
Chicken broth	3	1.1; 1.3; 1.5	(lipid content unknown)	NR	NR
Coffee	2	ND(0.2); 0.08	NR	NR	NR
Orange juice	3	ND(0.3); ND(0.3); ND(0.4)	NR	NR	NR

NOTE: ND = Not detected; NR = Not reported

[a] Values in parentheses are detection limits.

Sources: Henry et al. (1992); LaFleur et al. (1990)

Table 4-4. Summary of Schecter et al. (1993) Data on U.S. Foods

	TEQ (pg/g)[a] Assuming ND = 0.5 DL	TEQ (pg/g)[a] Assuming ND = 0	Number of Samples[b]
Haddock Fillet	0.03	0.02	2
Crunchy Haddock	0.13	0.13	1
Perch	0.24	0.24	1
Cod	0.023	0.012	1
Ground Beef	1.5	1.5	1
Beef Rib Sirloin Tip	0.04	0.04	1
Beef Rib Steak	0.65	0.65	1
Pork Chop	0.26	0.26	1
Cooked Ham	0.029	0.024	1
Lamb Sirloin	0.4	0.4	1
Lebanon Bologna	0.12	0.11	1
Chicken	0.03	0.03	1
Cottage Cheese	0.04	0.04	1
Blue Cheese	0.73	0.70	1
Cream Cheese	0.38	0.38	1
American Cheese	0.31	0.31	1
Heavy Cream	0.35	0.33	1

ND = nondetect; DL = detection limit

[a] Concentrations reported on whole food, wet weight basis.
[b] Samples collected from a supermarket in New York.

Source: Schecter et al. (1993)

ppt for beef on a wet weight basis. If nondetectable concentrations are assumed to be zero; the estimated total TEQ for beef is estimated to be 0.29 ppt. All of the pork samples analyzed by CARB, NCASI, and Schecter et al. (1993) had at least one 2,3,7,8-substituted CDD/F at detectable concentrations. The hepta- and octa-chlorinated dioxins and furans were detected most frequently, and only one congener was not detectable in any of the samples analyzed. Using an assumed lipid content of 15 percent and one-half the detection limit to represent nondetectable concentrations, the estimated total whole weight TEQ for pork is 0.26 ppt. If nondetectable concentrations are assumed to be zero, the estimated TEQ for pork is 0.10 ppt. Therefore, the TEQ concentration for pork is expected to be between 0.10 ppt and 0.26 ppt.

Chicken and Eggs

Background TEQ concentrations for chicken are based on data from CARB (Stanley and Bauer, 1989) and Schecter et al. (1993). Nine composite chicken samples were analyzed for 16 2,3,7,8-substituted CDD/F congeners. All chicken samples contained detectable concentrations of at least one CDD/F congener. The hepta-chlorinated CDD/Fs and OCDD were detected most frequently, and 5 of the 16 congeners were not detected in any of the 9 chicken samples. The total background whole weight TEQ for chicken is estimated to be 0.19 ppt using an assumed lipid content of 15 percent and one-half the detection limit to represent the concentration of nondetectable congeners. Using zeros to represent nondetectable concentrations, the estimated total whole weight TEQ for chicken is 0.07 ppt. Therefore, the TEQ for chicken is expected to be between 0.07 ppt and 0.19 ppt. Background TEQs for eggs are based on data from CARB (Stanley and Bauer, 1989). For eggs, seven out of eight composite samples had no detectable concentrations of 2,3,7,8-substituted CDD/F congeners. Only one sample contained detectable concentrations of OCDD, 2,3,7,8-TCDF, and 1,2,3,4,6,7,8-HpCDF. Using one-half the detection limit for nondetectable concentrations, the estimated total TEQ for eggs is 0.14 ppt; but using zero for the nondetectable concentrations, the estimated TEQ for eggs is only 0.0004.

Milk and Milk Products

Background levels of CDD/Fs in U.S. milk are based on a very limited data set. CARB (Stanley and Bauer, 1989) analyzed eight packaged milk samples and found an average of 0.06 ppt TEQ. Becuase these samples may have been impacted by leaching of CDD/Fs from packaging materials, they were eliminated from the analysis of background concentrations conducted for this report.

LaFleur et al. (1990) analyzed a single background milk sample for 2,3,7,8-TCDD and 2,3,7,8-TCDF. The sample contained 2,3,7,8-TCDD at a concentration of 0.0018 ppt and nondetectable concentrations of 2,3,7,8-TCDF. Based on the LaFleur et al. (1990) data, the TEQ for these two congeners is estimated to be 0.0018 ppt whether one-half the detection limit or zero is used to represent the nondetectable concentration of 2,3,7,8-TCDF.

EPA (1991b) collected milk samples from several sites in the vicinity of a municipal waste incinerator in Rutland, Vermont, and two background samples from a dairy farm 123 kilometers from the incinerator where no obvious industrial sources of CDD/F were present. All samples were taken from bulk storage tanks at the farms. The report indicated that facility emissions could not be correlated with the levels of CDD/F and other contaminants measured in various environmental media. For all milk samples, the majority of the congeners were not detected. It was reported that only OCDD was consistently detected at levels from 0.2 to 2.4 pg/g in the farms near the facility. The levels in milk from the three farms near the facility ranged from about 0.2 to 0.4 pg of TEQ/g whole milk, and the TEQ for the background samples collected from the distant farm was 0.12 pg/g. The TEQs were calculated by EPA (1991b) by setting the nondetects equal to the detection limit. The 0.12 ppt TEQ background value estimated by EPA is nearly 2 orders of magnitude higher than the TEQ for milk based on the NCASI data. (This is probably due largely to the incomplete congener analysis conducted by LaFleur et al.) Examination of the raw data supporting this study indicated that all of the CDD/F congeners in the background sample were nondetectable. Consequently, if nondetects are set to zero, the total background TEQ for milk would be zero. If half the detection limits are used to

calculate the total TEQ level, the estimated value is 0.07. Therefore, the total background TEQ level for milk is expected to be between zero and 0.07 pg/g.

Some idea of the total TEQ level of CDD/F in milk samples can be gained by assuming that levels in beef fat are similar to levels in milk fat. This assumption implies that the differences in feeding/raising practices of dairy cattle vs. beef cattle do not cause substantial differences in CDD/F exposure. Beef contains approximately 20 percent fat, and whole milk is about 4 percent fat. Thus, on a whole food basis, CDD/F levels in beef should be about five times higher than in milk. Support for this concept can be seen in the German data presented in Table 4-2. This table shows that the TEQ level in milk fat is 1.35 ppt and in beef fat is 1.08 ppt. On this basis, the North American data for beef (0.48 ppt of TEQ) suggest that milk would be about 0.1 ppt of TEQ. This lends support to the background level reported in EPA (1991b) of 0.12 ppt, based on only two samples.

Schecter et al. (1992) reported on the analysis of 2,3,7,8-substituted CDD/Fs in U.S. dairy products. Cottage cheese, soft cream cheese, and American cheese samples were selected randomly from New York supermarkets and analyzed on a wet-weight basis. All of the dairy products sampled had at least 13 detectable congeners out of the 17 evaluated. Only one congener (1,2,3,7,8,9-HxCDF) was not detectable in any of the five dairy products. Based on these data, the total background TEQ concentration of dairy products is estimated to be 0.36 ppt if one-half the detection limit is used to represent nondetectable concentrations and 0.35 if zero is used to represent nondetectable concentrations.

Fruits and Vegetables

Data on CDDs and CDFs in U.S. fruit and vegetable products are extremely limited. The Ministry of the Environment, Ontario, conducted a study of CDDs and CDFs in locally produced and imported fruits and vegetables, some of which originated in the United States (Ministry of the Environment, 1988; Birmingham et al., 1989). Samples of fresh apples, peaches, potatoes, tomatoes, and wheat products were analyzed. In general, the minimum detection limits for these analyses were less than 1 ppt. The report indicated that "fruit and vegetable samples were substantially free of PCDD and PCDF residues,

especially the more toxic tetra, penta, and hexachlorinated forms" (Ministry of the Environment, 1988). OCDD was the only congener detected in any of the samples. One apple and one peach sample contained detectable OCDD concentrations (8 ppt and 0.6 ppt, respectively). Detectable OCDD concentrations were found at concentrations ranging from 1 to 3 ppt in potatoes and 0.6 to 0.7 ppt in wheat samples. None of the tomato samples contained detectable levels of any CDD or CDF congeners. Based on these results, Birmingham et al. (1989) estimated the TEQs for fruits, vegetables, and wheat products to be 0.004 ppt, 0.002 ppt, and 0.0007 ppt, respectively.

As discussed in Volume III, dioxin contamination of fruits and vegetables is thought to occur primarily via particle deposition or vapor adsorption onto outer layers with little penetration to inner portions. Plant uptake from the soil via the roots is generally considered negligible. However, the work of Hülster and Marschner (1993) indicates that zucchini and pumpkins were exceptions. For these plant species, it appears that root uptake occurs and leads to a uniform concentration within the fruit. The concentration of CDDs and CDFs in zucchini squash grown on "uncontaminated" soil (0.4 ppt TEQ soil concentration) ranged from 0.5 to 0.7 ppt TEQ dry weight. These reported values may be converted to whole weight TEQ concentrations by using an assumed moisture content of 93.7 percent (USDA, 1979-1984). The resulting range of whole weight concentrations for zucchini is 0.03 to 0.04 ppt TEQ. Müller et al. (1993) also evaluated CDDs and CDFs in vegetables (carrots, lettuce, and peas) grown at both contaminated plots and control plots. For the control plots, the highest levels of CDDs and CDFs were observed in carrot peels: 0.55 ppt TEQ dry weight, or 0.07 ppt TEQ whole weight, assuming a moisture content for carrots of 87.8 percent (USDA, 1979-1984). Lower concentrations were observed in samples from the cortex of the carrots, indicating that the "contamination source for the peel of carrots is the soil" (Müller et al., 1993). Lettuce concentrations ranged from 0.1 to 0.4 ppt TEQ dry weight. This is equivalent to a whole weight concentration range of 0.005 to 0.018 ppt TEQ, assuming a moisture content of 95.4 percent for lettuce (USDA, 1979-1984). Concentrations in peas from contaminated plots ranged from 0.04 to 0.12 ppt TEQ dry weight (0.004 to 0.013 ppt TEQ whole weight, assuming a moisture content of 88.9 percent). Lower concentrations in peas (i.e., close to the detection limit; exact

value not given) were reported for control plots. Similar data for vegetables grown in the United States were not available.

Vegetable Oil

The high fat levels in vegetable oil suggest that it may be important to consider as a source of human exposure. Vegetable oils can be made from a variety of plants including corn, olives, peanuts, sunflower seeds, safflower seeds, linseed, and cotton seed. Many of these items are protected from atmospheric deposition, which implies that their CDD/F levels would be low. However, Theleen (1991) estimated that vegetable oil could contribute about 10 percent of a person's total daily intake in the Netherlands (14 of 120 pg TEQ/d). This estimate was based on the Fürst et al. (1990) study that found nondetects for most congeners except some of the higher chlorinated congeners of CDD and CDF (detection limit = 0.5 ppt). Half the detection limit was used for the nondetects, and most of the congeners were not detected. Consequently, the actual value could be much lower. No data could be found on CDD/F levels in vegetable oil in North America.

U.S. Food Summary

The U.S. food data are summarized in Table 4-5. The background TEQ estimates are presented first assuming that nondetects equal half the detection limits and second assuming that nondetects equal zero. For food groups such as eggs, a wide range of TEQ estimates are seen indicating a high percent of nondetects among individual congeners. The upper mean TEQ estimates are generally comparable to the TEQ estimates derived from studies conducted in Germany and Canada (as discussed below). These studies did not report TEQs based on assuming nondetects equal to zero but did report many nondetects in some food groups. In summary, the limited number of U.S. food samples and the high incidence of nondetects make an uncertain basis for estimating national background levels. However, the general agreement with food level estimates reported for Canada and Germany provides some reassurance that these U.S. values are reasonable. It is clear, however, that a large survey is needed to confirm residue levels of CDD/F in the U.S. food supply. For the purposes of calculating background exposures to CDD/Fs via

Table 4-5. Summary of CDD/CDF Levels in U.S. Food (pg/g fresh weight)

	Mean TEQ Assuming ND=0.5 DL	Mean TEQ Assuming ND=zero	Number of Samples	Reference
Beef	0.48	0.29	14	Stanley & Bauer (1989), LaFleur et al. (1990), Schecter et al. (1993)
Pork	0.26	0.10	12	Stanley & Bauer (1989), LaFleur et al. (1990), Schecter et al. (1993)
Chicken	0.19	0.07	9	Stanley & Bauer (1989), Schecter et al. (1993)
Eggs	0.13	0.0004	8	Stanley & Bauer (1989),
Dairy Products	0.36	0.35	5	Schecter et al. (1993)
Milk	0.07	0	2	U.S. EPA (1991b)
Fish	1.2	0.59	60	U.S. EPA (1992)

ND = Nondetect; DL - Detection Limit

dietary intake, the upper-range background TEQs (i.e., those calculated using one-half the detection limit for the nondetects) were used (See Chapter 5.)

4.6.3 European Food

Relatively extensive multiyear surveys of the levels of CDDs and CDFs in food are being undertaken in Sweden and the United Kingdom (de Wit et al., 1990 and Startin et al., 1990). The most extensive investigations reported to date that involve testing of a variety of randomly selected food samples collected within the framework of official food control have been performed in the Federal Republic of Germany (Beck et al. 1989; Fürst et al., 1990). The detailed results of these studies are included in Appendix B. Fürst et al. (1990) analyzed 107 food samples collected in Germany. The results of this study are presented in Table 4-6. All samples, except some of the milk, were randomly collected during official food monitoring programs. The authors speculated that a source may have been near the areas where the milk samples were collected because they appeared higher than other milk tested in Germany which showed levels around 1 ppt TEQ. In a later report, Fürst et al. (1991) reported that a much larger survey of dairies in Germany had been completed. This survey analyzed 168 samples of milk and milk products collected at dairies prior to bottling. They found an arithmetic mean of 1.35 pg of TEQ/g of fat. TEQs in these studies were estimated by assuming that nondetects equalled half the detection limits. The percent detected was not reported. Fürst et al. (1991) provided a summary of the results of several European studies. The data summaries relevant to background levels in meat and dairy products from Fürst et al. (1991) are presented in Table 4-7. Fürst et al. (1991) report that information on CDD and CDF levels in vegetables and fruits is scarce and that the available data indicate a background of below 1 ppt.

Beck et al. (1989) analyzed 12 food samples collected randomly from food markets in West Berlin, Germany. Chicken, eggs, butter, pork, ocean perch, cod, herring, vegetable oil, cauliflower, lettuce, cherries, and apples were analyzed for CDD/Fs. CDD/Fs were detected in samples of animal origin in the ppq to ppt range (fat weight basis). No CDD/F congeners were detected at a detection limit of 0.01 ppt (whole weight basis) in samples of plant origin.

Table 4-6. CDD/CDF Levels in German Food

	Mean TEQ[a] (pg/g fat)	Number of Samples
Cow's Milk	1.35	168
Cheese	0.98	10
Butter	0.66	5
Beef	1.69	3
Veal	3.22	4
Pork	<0.4	3
Sheep	1.23	2
Chicken	1.41	2
Canned Meat	1.29	2
Lard	0.47	4
Fresh Water Fish	13.25	18
Salt Water Fish	16.82	15
Fish Oil	2.64	4
Cod Liver Oil	13.31	4
Salad Oil	<0.4	4
Margarine	<0.4	6
Infant Formula	0.5	10

[a] TEQ computed using one-half the detection limit for nondetects.

Sources: Milk data based on Fürst et al. (1991); other data from Fürst et al. (1990).

Table 4-7. CDD/CDF Background Levels in Some European, Canadian, and New Zealand Food

Country	Food	Source	pg TEQ/g fat
Germany	Cow's milk	Background contamination	1.0 - 2.8
	Cow's milk	Consumer's milk	0.8 - 2.6
United Kingdom	Cow's milk	Rural area	1.3
Netherlands	Cow's milk	Background contamination	0.7 - 2.5
New Zealand	Cow's milk	Background contamination	0.18 - 0.22
Germany	Pork		0.5
	Beef		3.5
	Veal		7.4
	Sheep		2.0
	Poultry		2.3
	Canned Meat		1.7
	Lard		0.8
Canada	Beef		2.9
	Pork		0.2
	Poultry		2.6

Source: Furst et al. (1991)

Theelen et al. (1993) collected food products from various locations in the Netherlands and analyzed them for 2,3,7,8-chlorine substituted dioxins, furans, and planar PCBs. Meat samples were collected from slaughter houses throughout the Netherlands. Fish, mixed meats, and cheeses were gathered at various grocery stores. Mixtures of foods in these categories were prepared based on the proportion of the average annual consumption rate that different food items in these categories represented. The food industry provided purified oils and fats. Mixtures of these items were also prepared in proportion to their annual use in the Netherlands. The concentration of CDD/Fs in these food products are presented in Table 4-8.

4.6.4 Canadian Food

Birmingham et al. (1989) analyzed CDD/F residues in food collected in Ontario, Canada. Most of the food was grown in Canada, although some was from the United States. They reported analyzing 25 composite samples from 10 food groups. The precise number of samples in each food group was not reported. No TeCDD, PeCDD, HxCDD, TeCDF, or PeCDF were found at detection limits of 0.1 to 7 ppt. Low ppt levels of some of the higher chlorinated CDD/Fs were detected in some foods. TEQ levels were also estimated for the major food groups. However, as shown in Table 4-9, these data were reported on a homolog basis. It is unclear what procedure was used to convert the homolog data to TEQ. The text implies that nondetects were treated as zero for purposes of estimating TEQ. In addition to the animal food data shown in Table 4-9, measurements were also made in potatoes, apples, tomatoes, peaches, and wheat. Only OCDD was detected at levels ranging from 0.6 to 8 pg/g fresh weight. The TEQ totals for vegetables were reported as 0.004 ppt for fruit, 0.002 ppt for vegetables, and 0.0007 ppt for wheat-based products. The procedure used to develop these TEQ estimates was not clear.

4.7. CONCENTRATIONS IN AIR

Tables B-14 through B-16 (Appendix B) contain summaries of data from studies of ambient air measurements of CDDs, CDFs, and PCBs in the United States and Europe. Environmental levels of PCBs in air are based on a single source of information (Hoff et al.,

Table 4-8. Concentrations of Dioxins and Furans in Food from the Netherlands

Food Category	CDDs/CDFs (pg TEQ/g fat)
Beef	1.75
Cow's Liver	5.7
Pork	0.43
Pig's Liver	15.3
Poultry	1.65
Chicken's Liver	3.25
Mutton	1.85
Horse Meat	13.85
Game [a]	16.8
Butter	1.8
Cheese [a]	1.4
Nuts [a]	0.2
Cereals [a]	0.34
Eggs	2.0
Fatty Sea Fish [a]	6.65
Lean Fish [a]	48.65
Eel	28.0
Fresh Water Fish [a]	2.4
Mixed Meat Product [a]	0.67
Dairy Products	1.58
Soy Bean Oil	0.025
Rape-Seed Oil	0.006
Palm Oil	0.030
Sunflower Oil	0.006
Coconut Fat	0.024
Palm Fat	0.010
Fish Oil	2.2
Items with Vegetable Oil [a]	0.02
Items from Food Industry [a]	0.41

[a] A proportional mixture of food items was analyzed.
Source: Theelen et al. (1993)

Table 4-9. Maximum CDD/CDF Levels in Foods Collected in Canada (pg/g fresh weight) as Reported by Birmingham et al. (1989)

	Eggs	Beef	Milk Products	Pork	Chicken
TCDD	ND	ND	NR	ND	ND
PeCDD	ND	ND	NR	ND	ND
HxCDD	ND	ND	NR	ND	ND
HpCDD	ND	ND	NR	ND	15
OCDD	8[a]	24[a]	NR	ND	210
TCDF	ND	ND	NR	ND	ND
PeCDF	ND	ND	NR	ND	ND
HxCDF	5[a]	ND	NR	ND	ND
HpCDF	7[a]	ND	NR	ND	ND
OCDF	12[a]	ND	NR	ND	ND
TEQ	0.59	0.29	0.11	0.03	0.39

NR = Not Reported.
ND = Not Detected; detection limites ranged from 0.1 to 0.7 pg/g.
[a] Data for foods of U.S. origin collected in Canada.

Source: Birmingham et al. (1989).

1992). Relatively few studies have been conducted to measure ambient air levels of CDDs/CDFs because of the low analytical detection limits required to detect the expected low concentrations of specific CDD/CDF congeners. These detection limits in ambient air samples were not achieved until the mid 1980s. To obtain subparts-per-trillion levels of analytical detection, sampling relatively large volumes of air (e.g., 350 to 450 cubic meters of ambient air over a 24-hour period) is required. The results of several of these recent studies are summarized in the following paragraphs.

4.7.1. U.S. Data

The most extensive ambient air monitoring study of CDDs/CDFs conducted to date is a multiyear monitoring effort conducted at eight sampling locations in the Southern California area by the Research Division of the California Air Resources Board from December 1987 through March 1989 (Hunt et al., 1990). The monitoring network "included a number of sites situated in primarily residential areas (San Bernadino, El Toro, and Reseda), as well as several sites in the vicinity of suspected sources of CDDs/CDFs (Cal. Trans, Commerce, North Long Beach, and West Long Beach)." The seven sites mentioned above were classified as urban locations by the definitions used in this document, while one site was classified as an industrial site (i.e., Carson--on site at manufacturer of gas cooking equipment). Additionally, four of the eight sites were part of the South Coast Air Quality Management District (SCAQMD) monitoring network. All totaled, there were nine sample collection intervals throughout this study. "Typically, five to seven stations were in contemporaneous operation during a particular session" (i.e., samples were not collected from each location at each interval). Total tetra- through octa-chlorinated CDDs and CDFs were screened for in the study as well as various 2,3,7,8-substituted CDD and CDF congeners. A total of 34 analyses were performed throughout the study for all congeners except for OCDD and OCDF, respectively, for which only 31 analyses were performed. Samples were collected over a maximum of seven intervals at each site throughout the study (i.e., Reseda and El Toro--six dates, duplicate samples on one date), while a sample was collected from the Commerce site during only a single collection interval. Sample collection intervals generally averaged 24 hours in duration.

Generally, higher substituted CDD and CDF congeners accounted for the majority of positive samples containing quantifiable CDD/CDF residues in this study (i.e., Total HxCDD/HxCDF and above). In fact, over 90 percent of the samples collected contained quantifiable levels of 1,2,3,4,6,7,8-HpCDD, Total HpCDD, and OCDD. Additionally, approximately 50 to 70 percent of the samples collected contained quantifiable levels of Total HxCDD; 2,3,7,8-TCDF; Total TCDF; Total PeCDF; Total HxCDF; 1,2,3,4,6,7,8-HpCDF; Total HpCDF; and OCDF. For all other congeners, quantifiable residues were detected in less than 25 percent of the samples collected. All CDD congener concentrations ranged from nonquantifiable levels (low limit of 0.0026 pg/m^3) to an upper limit of 18.0 pg/m^3. Additionally, CDF congener levels ranged from nonquantifiable levels (low limit of 0.0040 pg/m^3) to an upper limit of 2.70 pg/m^3.

According to Hunt et al.(1990), "The highest concentration of CDDs/CDFs congener class sums (Cl_4-Cl_8) and 2,3,7,8-substituted species were noted during a period predominated by off-shore air flows in December 1987, suggesting a regional air mass and transport phenomena. Concentrations of the CDDs/CDFs were diminished markedly in subsequent sessions where air flow patterns were primarily off-shore or of coastal origin." Hunt et al. (1990) indicated that the "CDD/CDF congener profiles (Cl_4-Cl_8) and 2,3,7,8-substituted isomeric patterns strongly suggest combustion source influences in the majority" of the samples collected.

In a long-term study of CDD/Fs in the ambient air around Bloomington, Indiana, methods were developed for measuring individual CDD/Fs at concentrations as low as 0.001 pg/m^3 (Eitzer and Hites, 1989). Total CDD/F concentrations were 0.480 pg/m^3 and 1.360 pg/m^3 for the vapor phase and the particle-bound phase, respectively. For individual congeners, CDFs were found to decrease in concentration with increasing levels of chlorination, and CDD concentrations were found to increase with increasing levels of chlorination (Eitzer and Hites, 1989).

4.7.2. European Data

Clayton et al. (1993) conducted a study of CDDs and CDFs in the ambient air of three major cities and an industrial town in the United Kingdom. The annual average TEQ

concentrations of CDDs and CDFs ranged from 0.04 to 0.10 pg/m^3. The hepta- and octachlorinated dioxin congeners contributed the most to the total concentration of 2,3,7,8-substituted CDD/Fs, and a large number of nondetect values were reported for the tetra-, penta-, and hexachlorinated dioxins. The congeners that contributed most to the total TEQ concentrations were 2,3,7,8-TCDF; 1,2,3,4,7,8-; 1,2,3,6,7,8-; and 2,3,4,6,7,8-HxCDF. These values are relatively consistent with the concentrations in ambient German air observed by Liebl et al. (1993) and König et al. (1993a). Liebl et al. (1993) analyzed ambient air samples collected from 10 sites in Hessen, Germany, from 1990 through 1992. Concentrations ranged from 0.04 to 0.15 pg TEQ/m^3. The higher concentrations were presumed to result from direct local industrial sources. König et al. (1993a) collected air samples from six sites located in Hessen, Germany. CDD/F concentrations ranged from 0.048 pg TEQ/m^3 at a rural reference site to 0.146 pg TEQ/m^3 at an industrial site. The results of the study also indicated that concentrations of CDDs and CDFs are typically higher in the winter than in the summer. Sugita et al. (1993) also observed higher concentrations of CDDs and CDFs in winter than in summer in an ambient air study in urban Japan. The average concentration of CDDs and CDFs was 0.788 pg TEQ/m^3 in the summer and 1.464 pg TEQ/m^3 in winter.

In a Swedish study, air samples were collected from a city center, suburb, remote countryside, and open coastal area (Broman et al., 1991). Analyses of the samples for dioxins and furans indicated that the concentrations of these compounds decreased with increasing distance from the city center. Total CDD/F concentrations were 1.40 pg/m^3, 1.10 pg/m^3, 0.40 pg/m^3, and 0.22 pg/m^3 for the city center, suburb, countryside, and open coastal areas, respectively. Similar patterns of decreasing concentrations with increasing distances from urban areas were also observed for individual CDD/F congeners (Broman et al., 1991). In a study of ambient air concentrations of CDDs and CDFs in Flanders, samples were collected and analyzed at rural, industrial, and urban sites (Wevers et al., 1993). Average ambient air concentrations ranged from 0.0696 pg TEQ/m^3 at a rural site to 0.254 pg TEQ/m^3 at a site believed to be influenced by a chemical industry and a highway.

PCBs have also been evaluated in European air samples (Halsall and Jones, 1993; König et al., 1993b). Halsall and Jones (1993) monitored urban air at two sites in the United Kingdom. The annual mean total PCB concentrations were 520 and 590 pg/m^3. PCBs existed in ambient air predominantly in the vapor phase. This study also indicated that summer PCB concentrations were higher than winter concentrations. These researchers attributed the differences in seasonal patterns to volatilization from soil during summer months. Ambient air concentrations of PCBs in Hessen, Germany, ranged from 350 to 1630 pg/m^3 during the period of 1990 to 1992 (König et al., 1993b). Urban areas characterized by industry and/or heavy traffic had the highest PCB concentrations in ambient air.

4.7.3. Air Summary

Based on the limited ambient air measurements that have been made in selected cities in the United States and Europe, there appears to be good agreement with respect to the magnitude of specific congeners of CDDs and CDFs in urbanized areas in the United States and Europe. Most of these measurements tend to be very close to the current analytical detection limit. This increases the probability that congeners indicated as not detected (ND) may actually be present.

A total of 84 samples from the studies summarized in Tables B-14 and B-15 was selected as representative of "background" conditions in the United States. Samples collected from pristine sites and from rural and urban locations not expected to be impacted by industrial point sources were assumed to represent "background" conditions. The mean TEQ level for these 84 samples is 0.095 pg/m3 assuming that values reported as not detected are equal to one-half the detection limit.

Based on the results of European studies, ambient air concentrations of CDDs and CDFs appear to be similar to those found in the United States. For the purposes of this study, a TEQ value of 0.10 pg/m^3 was used to represent concentrations in Europe. This value represents the mean of the midpoints of the European studies for which TEQ concentrations were reported (Clayton et al. 1993; Liebl et al. 1993; König et al. 1993a;

Wevers et al. 1993). Data for these European studies are not included in Tables B-14 and B-15 because individual congener data were not reported.

It is interesting to compare these values with the CDD/CDF concentrations in air recently measured by Lugar (1993) in and around McMurdo Station, Antarctica, a logistics and staging facility with a population of about 1,100. Four locations were sampled: a site upwind of the station, downwind of the station, in the center of the station, and a remote unpopulated island 30 kilometers distant from the station. CDDs/CDFs were not detected in the samples from the upwind site (congener detection limits ranged from <0.01 to 0.03 pg/m^3) and the remote island sites (congener detection limits ranged from 0.001 to 0.008 pg/m^3) and only sporadically at the downwind site (some congeners detected in three of five samples). CDDs/CDFs were detected in all five samples collected from the station center site (mean TEQ concentration of 0.0153 pg/m3).

4.8. TEMPORAL TRENDS

Small amounts of dioxin-like compounds may be formed during natural fires suggesting that these compounds may have always been present in the environment. However, it is generally believed that much more of these compounds have been produced and released into the environment in association with man's industrial and combustion practices, and as a result, environmental levels are likely to be higher in modern times than they were in prior times. However, the trend may now be reversing (i.e., releases and environmental levels may be gradually decreasing) due to changes in industrial practices (Rappe, 1992). As discussed in Chapter 3, the potential for environmental releases of dioxin-like compounds has been reduced due to the switch to unleaded automobile fuels (and associated use of catalytic converters and reduction in halogenated scavenger fuel additives), process changes at pulp and paper mills, improved emission controls for incinerators, and reductions in the manufacture and use of chlorinated phenolic intermediates and products.

Smith et al. (1992, 1993) analyzed sediment core layers from Green Lake, located near Syracuse, New York, to determine temporal trends in the deposition of CDDs and CDFs since the beginning of the industrial era (i.e., circa 1860). This deep lake (200-foot

depth) is thought to be impacted only by atmospheric deposition because no industrial inputs are present and motorboats are not allowed. Relatively constant but low concentrations of CDDs and CDFs (10 ng/kg or less) are observed in sediments deposited from 1860 to 1930. However, concentrations increase rapidly thereafter, reaching a peak in the mid-1960s when total CDD concentrations exceeded 1,300 ng/kg and total CDF concentrations exceeded 250 ng/kg. The concentrations of CDDs and CDFs have rapidly declined since the mid-1960s, and now (1986-1990) are measured at 750 ng/kg as total CDD/CDF. The authors speculate that the decline may be due to the switch to unleaded fuels for vehicles. Similar trends have been reported by Czuczwa and Hites (1984) for Great Lakes sediment.

Rappe (1991) reports testing of archived soils and plants collected in southeast England between 1846 and 1986. CDDs and CDFs were found in all samples and showed generally increasing levels of dioxins. Rappe further notes that the congener pattern is typical of those for combustion sources until about 1950 when the pattern becomes more dominated by hepta- and octa-CDDs corresponding to increases in production of chlorinated compounds. Schecter (1991) analyzed ancient liver tissues (estimated to be 100- to 400-years old) recovered from frozen bodies of Native American (Eskimo) women. He found that the dioxin levels were much lower than those commonly found in livers of people currently living in industrial areas.

Studies that may be used to assess temporal trends in human exposure to dioxins and furans are extremely limited. The use of indirect exposure assessment techniques for detecting temporal trends is difficult because large-scale, long-term, nationally-representative environmental monitoring for dioxins and furans has not been conducted. Short-term studies are generally not comparable because of differences in sampling protocols and analytical techniques used in these studies. A potentially useful study for evaluating changes in human exposure over time is EPA's National Human Adipose Tissue Survey (NHATS). The purpose of NHATS is to monitor the human body burden of selected chemicals in the general U.S. population (U.S. EPA, 1991a). NHATS uses direct measurement techniques to estimate exposures. Nationwide samples of adipose tissue are collected from surgical patients and autopsied cadavers and analyzed annually. In 1982,

broadscan analysis of composited adipose tissue specimens revealed that chlorinated dioxins and furans could be detected and quantified in the U.S. population across all geographic regions and age groups (U.S. EPA, 1986). In 1987, NHATS specimens were also analyzed for dioxins and furans making temporal comparisons possible. Statistical analyses were performed to determine if significant differences existed between the concentrations of these compounds in 1982 and 1987 adipose tissue specimens.

Table 4-10 presents the estimated national average concentrations for the two time periods and the relative changes from 1982 to 1987. The estimated concentrations of 1,2,3,7,8-PeCDD; 2,3,4,7,8-PeCDF; and HxCDD in human adipose tissue were significantly lower in 1987 than in 1982 (U.S. EPA, 1991a). Similar survey designs were used in the two studies, but changes in some of the analytical methods were made in 1987 that may account for some of the differences in estimated concentrations. These changes include lower limits of detection and the use of additional internal quantitation standards that provided more accurate measurements. The levels of 2,3,7,8-TCDD; 1,2,3,4,6,7,8-HpCDD; and OCDD were also lower in 1987 than in 1982, but the differences were not found to be statistically significant. No statistical comparisons were possible for 2,3,7,8-TCDF; HxCDF; 1,2,3,4,6,7,8-HpCDF; or OCDF because one or both of the annual estimates were based on data that did not meet the minimum criteria for statistical modeling (i.e., the chemical was not detected in at least 50 percent of the composites analyzed, and/or fewer than 30 composite samples were analyzed in each year). The results of this study indicate that exposure to certain dioxins and furan congeners may have decreased over this 5-year time period. However, further studies are needed to verify that these changes are not a result of protocol changes, but actual reductions in exposures.

4.9. SUMMARY OF CDD/CDF LEVELS IN ENVIRONMENTAL MEDIA AND FOOD

This chapter has summarized data on CDD/F levels in environmental media and food with emphasis on "background levels." Data representative of background conditions in environmental media are considered to be those collected in rural, pristine, and urban (air only) areas not believed to be impacted by any local sources (e.g., incinerators and

Table 4-10. Estimated National Average Concentrations of Dioxins and Furans from the 1982 and 1987 NHATS

	1982[a] (pg/g)	1987[a] (pg/g)	Difference[a] (pg/g)
2,3,7,8-TCDD	5.88 (0.534)	5.38 (0.330)	-0.499(0.628)
1,2,3,7,8-PeCDD	73.6 (20.0) [b]	10.7(0.426)	-62.9(20.0)
HxCDD [c]	122.0(20.1) [b]	86.8 (3.16)	-34.8 (20.3)
1,2,3,4,6,7,8-HpCDD	142.0 (24.8)	110.0 (3.73)	-31.6 (25.0)
OCDD	768.0 (79.7)	724.0 (28.6)	-43.9 (84.7)
2,3,4,7,8-PeCDF	35.4 (3.57) [b]	9.70 (0.800)	-25.7 (3.66)

[a] Standard errors of the estimated averages are in parentheses.

[b] The 1982 estimate is significantly higher than the 1987 estimate at the 0.05 level of significance.

[c] Analysis results for specific isomers of HxCDD and HxCDF were combined for comparisons.

Source: U.S. EPA (1991a)

highways). Only food data from the general food supply (i.e., collected from grocery stores) were used to represent background conditions (except fish). Tables B-17 through B-30 in Appendix B present the geometric and arithmetic averages of environmental background monitoring data for CDD and CDF congeners in various media, compiled from the published literature. The geometric averages are consistently lower than the arithmetic averages. This results from the fact that the data span several orders of magnitude with the distribution skewed toward the lower end due to the large number of not detected values. To calculate a total TEQ for all CDD/CDFs for each media, the arithmetic mean background concentration for each congener was multiplied by its respective TEF value, and individual TEQs for each congener were totaled. These total TEQs are presented at the end of Tables B-17 through B-30 and summarized in Table 4-11. These total background level TEQs are used in Chapter 5 to estimate typical exposure levels in the United States. Exposure levels for Europe are based on the levels of CDD/Fs in food reported by Fürst et al. (1990), and the levels in environmental media are based on data collected from several European countries.

Standard deviations of the total mean TEQs for each media were also calculated to depict the "range" of probable CDD/CDF levels in various media. Because the total TEQs were actually a summation of mean TEQs for various congeners, the use of typical methods for calculating standard deviations was not possible. Therefore, standard deviations were based on the standard deviation of the congener that contributed most to the total TEQ. The percentage deviation from the mean for that congener was applied to the total mean TEQ for all congeners combined. The congeners selected for use in the standard deviation estimates are presented in Table 4-12. The data in this table indicate that the pentachlorinated dioxins were the highest contributors to total TEQs in most foods in the United States.

The media levels presented in Table 4-11 are shown graphically in Figure 4-1. Except for the TEQ levels in European food which are based on data reported for German food by Fürst et al. (1990) and the TEQ levels in European air which are based on data repoted for air in Germany, Belgium and the United Kingdom by König et al. (1993), Liebl et al. (1993), Wevers et al. (1993), and Clayton et al. (1993), all other TEQ levels

Table 4-11. Summary of CDD/CDF Levels in Environmental Media and Food (whole weight basis)

Media	North America[a]	Europe[e,a]
Soil, ppt:	n=95	n=133
TEQ	7.96 ± 5.70	8.69
Sediment, ppt:	n=7	n=20
TEQ	3.91[b]	34.89[b]
Fish, ppt:	n=60	n=18
TEQ	1.16 ± 1.21	0.93[f]
Air, pg/m^3:	n=84	n=454
TEQ	0.0949 ± 0.24	0.108[g]
Water, ppq:	n=214	
TEQ	0.0056 ± 0.0079	NDA
Milk, ppt:	n=2	n=168
TEQ	0.07[c,d]	0.05[h]
Dairy, ppt:	n=5	n=10
TEQ	0.36 ± 0.29	0.08[i]
Eggs, ppt:	n=8	n=1
TEQ	0.135 ± 0.119	0.152[d]
Beef ppt:	n=14	n=7
TEQ	0.48 ± 0.99	0.32[j]; 0.61[k]
Pork, ppt:	n=12	n=3
TEQ	0.26 ± 0.13	<0.06[l]
Chicken, ppt:	n=9	n=2
TEQ	0.19 ± 0.29	0.21[l]

Footnotes:

NDA = No data available.

a Values are the arithmetic mean TEQs and standard deviations.

b Standard deviations could not be calculated because detection limits for most samples were not reported.

c Value was calculated from the raw data used in U.S. EPA (1991b) using half the detection limits for nondetects.

d Standard deviation could not be calculated because data were limited for the congener that contributed the most to the total TEQ.

e Soil, sediment, and air values based on data from a variety of European countries (see Tables B-17 to B-30); egg data based on Beck et al. (1989); and other food levels based on data from Germany (Fürst et al., 1990).

f TEQ calculated from Fürst et al. (1990) for fresh water fish by assuming 7% fat content (U.S. EPA, 1993).

g TEQ assumed to be the mean of the midpoints of the ranges reported in four European studies (Clayton et al., 1993; König et al., 1993a; Liebl et al., 1993; Wevers et al., 1993).

h TEQ calculated from Fürst et al. (1990) by assuming 4% fat content.

i TEQ calculated for cheese from Fürst et al. (1990) by assuming 8% fat content.

j TEQ for beef calculated from Fürst et al. (1990) by assuming 19% fat content.

k TEQ for veal calculated from Fürst et al. (1990) by assuming 19% fat content.

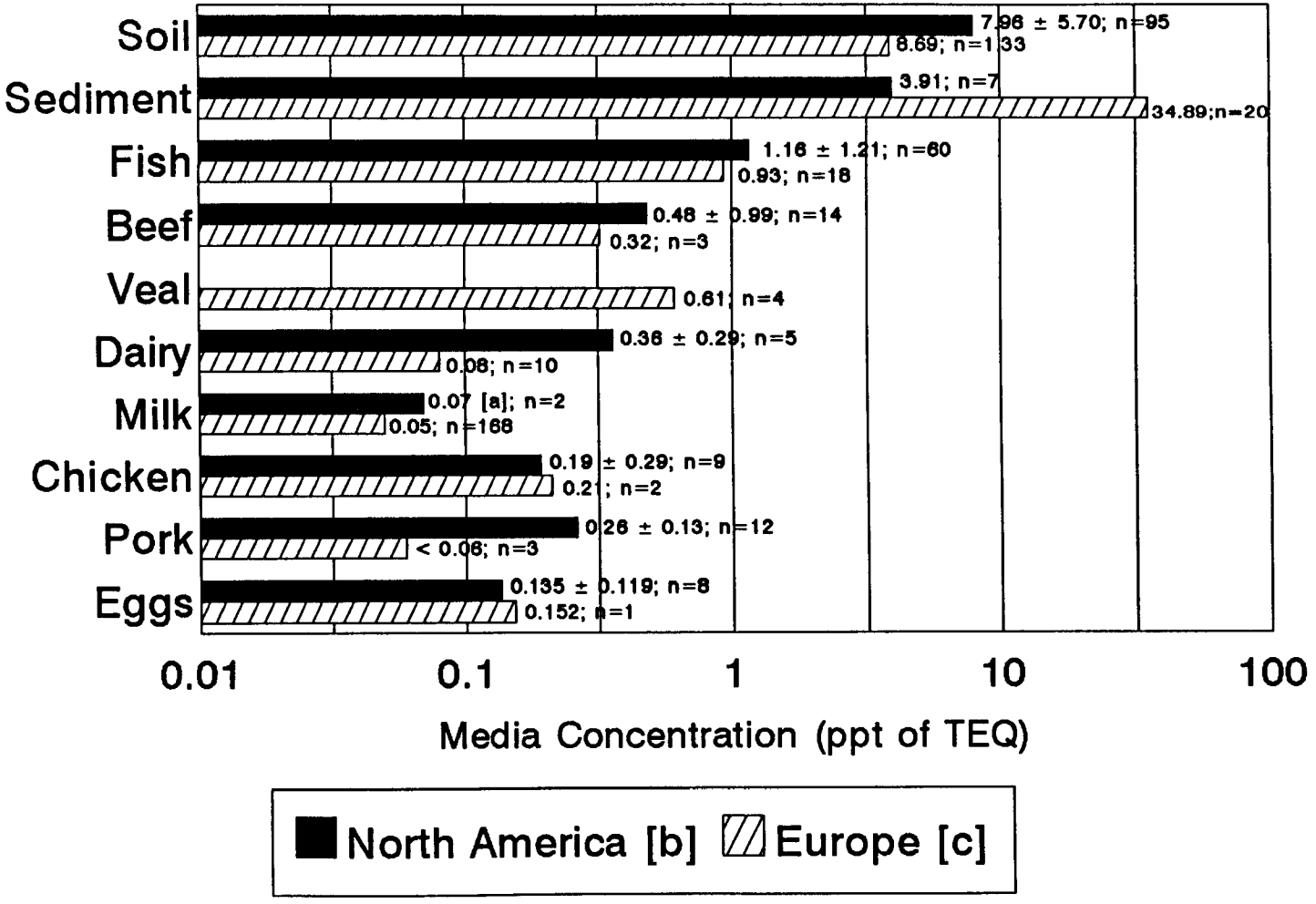
l TEQ calculated from Fürst et al. (1990) by assuming 15% fat content.

Table 4-12. CDD/CDF Congeners that Contribute the Highest Percentage of TEQ to the Total TEQ for All Congeners Combined

Media	North America	Percentage of Total TEQ
Soil	1,2,3,4,6,7,8-HpCDD	24.3
Sediment[a]	2,3,7,8-TCDD	80.8
Fish	2,3,7,8-TCDD	29.9
Air	1,2,3,7,8-PeCDD	16.7
Water[b]	OCDD	56.3
Milk	2,3,7,8-TCDD	32.4
Dairy	1,2,3,6,7,8-HxCDD	19.2
Eggs	1,2,3,7,8-PeCDD	29.9
Beef & Veal	1,2,3,7,8-PeCDD	23.2
Pork	1,2,3,7,8-PeCDD	30.3
Chicken	1,2,3,7,8-PeCDD	28.9

NOTE: Data were not available for all congeners in all media.
[a] Data available for 2,3,7,8-TCDD and 2,3,7,8-TCDF only.
[b] Data available for OCDD and OCDF only.

Figure 4-1 Background Environmental Levels in TEQ



[a] Based on an examination of raw data reported by EPA (1991b); [b] Based on N. American studies;
[c] Environmental media levels based on various European studies,
Food levels based on Furst et al (1990), Egg levels based on Beck et al (1989)

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presented in Figure 4-1 are based on the data analyzed in this study. The background TEQ levels of CDD/CDFs in water and air were found to be lower than in any of the other environmental media evaluated and were not included in Figure 4-1. For most media, the average levels appear to be similar between North America and Europe. However, differences were noted in three areas:

- **Sediment** - The background levels in Europe were estimated to be higher than North America. It should be noted, however, that only the 2,3,7,8-TCDD/F and OCDD/F congeners were analyzed for background sediment sites in the United States and Europe. The sediment data are quite variable and can be very high in impacted areas (i.e., 2,3,7,8-TCDD levels over 1000 ppt have been measured in industrial areas). Also, it was difficult to interpret whether some of the European data truly represent unimpacted areas. Thus, these differences may be due more to the weakness of the data base and interpretation difficulties, rather than real differences.

- **Dairy Products** - The dairy products data suggest that North America levels are higher than European. Dairy products include a wide variety of food items with varying amounts of fat. Thus, the CDD/F levels would vary correspondingly. Differences in the mix of dairy products used for the North America and European estimates could explain these differences.

- **Pork** - The pork data suggest that North America levels are higher than European levels. The low number of samples collected in Europe may mean this estimate is not representative.

In general, the differences noted above probably reflect the sparseness or inequalities in the data rather than real differences. The human tissue data (discussed in Section 5.4) suggest similar body burden levels in the North America, Europe, and other

industrial countries. Thus, it seems likely the media levels would also be similar. Large-scale market basket food surveys are clearly needed to confirm these levels.

4.10. MECHANISMS FOR ENTRY OF CDD/CDFS INTO THE FOOD CHAIN

CDD/Fs can enter aquatic systems directly from sources in effluent discharges, indirectly from deposition of CDD/Fs in the atmosphere onto water bodies, and in stormwater runoff from areas where dioxin-containing material has been land-applied or atmospherically deposited. For any given water body, the dominant transport mechanism will depend on site-specific conditions. Aquatic organisms will bioaccumulate CDD/Fs and thereby enter the aquatic food chain.

Based on information currently available, the primary mechanism by which dioxin-like compounds enter the terrestrial food chain is via atmospheric deposition and sorption of vapors. Deposition can occur directly onto plant surfaces or onto soil. Deposits onto the soil can enter the food chain via direct ingestion (e.g., soil ingestion by earthworms, fur preening by burrowing animals, incidental ingestion by grazing animals, etc). CDD/Fs in soil can become available to plants and thus enter the food chain by volatilization and vapor sorption or particle resuspension and adherence to plant surfaces. Although CDD/Fs in soil can adsorb directly to underground portions of plants, uptake from soil via the roots into above ground portions of plants is thought to be insignificant (McCrady et al., 1990).

Support for this air-to-food hypothesis is provided by Hites (1991) who concluded that "background environmental levels of PCD/F are caused by PCD/F entering the environment through the atmospheric pathway." His conclusion was based on demonstrations that the congener profiles in lake sediments could be linked to congener profiles of combustion sources. Further argument supporting this hypothesis is offered below:

- Numerous studies have shown that CDD/Fs are emitted into the air from a wide variety of sources and that CDD/Fs can be commonly detected in air at low concentrations. (See Chapters 3 and 4.)

- Studies have shown that CDD/Fs can be measured in wet and dry deposition in most locations including remote areas (Koester and Hites, 1992; Rappe, 1991).

- Numerous studies have shown that CDD/Fs are commonly found in soils throughout the world. (See Chapter 4.) Atmospheric transport and deposition is the only plausible mechanism that could lead to this widespread distribution.

- Models of the air-to-plant-to-animal food chain have been constructed. Exercises with these models show that measured deposition rates and air concentrations can be used to predict food levels that are similar to levels actually measured in food (Travis and Hattemer-Frey, 1991; also Chapter 7 of Volume III).

- Alternative mechanisms of uptake into food appear less plausible:

  - Uptake in food crops and livestock from water is minimal due to the hydrophobic nature of these compounds. Travis and Hattemer-Frey (1987, 1991) estimate water intake accounts for less than 0.01 percent of the total daily intake of 2,3,7,8-TCDD in cattle. Experiments by McCrady et al. (1990) show very little uptake in plants from aqueous solutions.

  - Relatively little impact on the general food supply is expected from soil residues that originate from site-specific sources such as sewage sludge and other waste disposal operations. Sewage sludge application onto agricultural fields is not a widespread practice. Waste disposal operations can be the dominant source of CDD/Fs in soils at isolated locations such as Times Beach, but are not sufficiently widespread to explain the ubiquitous nature of these compounds.

  - The release of CDD/Fs to the environment from the use of pesticides contaminated with CDD/Fs is beleived to have declined in recent years; however, the past and current impact of pesticide use on CDD/F levels in the food supply is uncertain. CDD/Fs have been associated with certain phenoxy herbicides most of which are no longer produced or have restricted uses. EPA has issued data call-ins requiring certain pesticide manufacturers to test their products for dioxin content. The responses, so far, indicate that levels in these products are below or near the limit of quantitation. (See Chapter 3.)

Current CDD/F levels in food resulting from the use of bleached paper products containing CDD/Fs appears to be minimal. In the early 1980s, testing showed that CDD/Fs could migrate from paper containers into food. Current levels in paper products are now much lower than in the early 1980s. Also, testing of products such as milk and beef prior to packaging has shown detectable levels which cannot be attributed to the packaging. (See Chapter 4.)

A related issue is whether the CDD/Fs in food result more from current or past emissions. Sediment core sampling indicates that CDD/F levels in the environment began increasing around the turn of the century, but also that CDF levels have been declining since about 1980 (Smith et al. 1992). Thus, CDD/Fs have been accumulating for many years and may have created reservoirs that continue to impact the food chain. As discussed in Chapter 3, researchers in several countries have attempted to compare known emissions with deposition rates. All of these studies (including this assessment) suggest that annual atmospheric depositions exceed annual emissions by a factor of 2 to 10. One possible explanation for this discrepancy in sources may be that volatilization or particle resuspension from these reservoir sources followed by atmospheric scavenging is responsible. These mass balance studies are highly uncertain, and it remains unknown how much of the food chain impact is due to current vs past emissions.

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5. BACKGROUND EXPOSURES TO CDD, CDF, AND PCB CONGENERS

5.1. INTRODUCTION

The purpose of this chapter is to assess background exposures to the dioxin-like compounds. Recent assessments of background exposures cited in the scientific literature are summarized, and background exposures that have been estimated from the data presented in Section 4 of this report are presented. The term "background," as applied to exposure, can be used to represent different concepts. Two common definitions are (1) the level of exposure that would occur in an area without known point sources of the contaminant of concern or (2) the average level of exposure occurring in an area whether sources are present or not. For the purposes of this document, "background" is defined as suggested in the first definition above. To the extent possible, background exposures estimated in this chapter are based on monitoring data obtained from sites removed from known contaminant sources (or food data representative of the general food supply). These data are considered to be the most useful for describing background exposure levels.

5.2. PREVIOUS ASSESSMENTS OF BACKGROUND EXPOSURES

Several researchers have published quantitative assessments of human exposures to CDDs and CDFs. Some of the more recent assessments are discussed below (Travis and Hattemer-Frey, 1991; Fürst et al.,1990; Fürst et al., 1991; Henry et al., 1992; Theelen, 1991; and Gilman and Newhook, 1991). It is generally concluded by these researchers that dietary intake is the primary pathway of human exposure to CDDs and CDFs. Over 90 percent of human exposure occur through the diet, with foods from animal origins being the predominant sources.

Travis and Hattemer-Frey (1991) estimated that the average daily intake of 2,3,7,8-TCDD by the general population of the United States is 34.8 pg/day. Ingestion exposures were estimated by multiplying the concentration of 2,3,7,8-TCDD in beef, milk, produce, fish, eggs, and water (estimated using the Fugacity Food Chain model) times the average U.S. adult consumption values for these products reported by Yang and Nelson (1986). The calculations assume that 100 percent of the 2,3,7,8-TCDD ingested are absorbed through the gut. Intake via inhalation was estimated by multiplying the concentration in

air times the amount of air inhaled per day (20 m^3) assuming that 100 percent of inhaled 2,3,7,8-TCDD are absorbed through the lung. The results of their assessment, summarized in Table 5-1, indicate that foods from animal origins comprise 95 percent of the estimated total daily exposure. These foods include milk and dairy products, beef, fish, and eggs. Exposure resulting from consumption of vegetables and other produce was estimated to account for 3.4 percent of the total intake. Exposure from ingestion of water, ingestion of soil, and inhalation of air together accounted for about 1 percent of the total daily intake.

Fürst et al. (1990) estimated human exposure to CDD/Fs based on the analysis of 107 food samples collected in the Federal Republic of Germany. The average daily TEQ intake was estimated to be 85 pg/person/day or 1.2 pg/kg body weight/day. Fürst et al. (1990) concluded that foods of animal origin contribute significantly to the human body burden of CDD/Fs. In a subsequent study, Fürst et al. (1991) assessed human exposure to CDDs and CDFs from foods using data from more than 300 randomly selected food samples and food consumption data reflective of consumption habits of the German population. These authors estimated that the German population's average daily intake of CDDs and CDFs from food is 158 pg TEQ per person of which 25 pg is 2,3,7,8-TCDD. Dairy products, meat and meat products (primarily beef), and fish and fish products each contribute about 32 to 36 percent of the daily intake of TEQ. Based on the levels of CDD/Fs observed in human samples, the average daily intake via food was estimated to be in the range of 1 to 3 pg TEQ/kg body weight.

Henry et al. (1992) of the U.S. Food and Drug Administration estimated the average exposure to the U.S. population from 2,3,7,8-TCDD through the food supply using the following assumptions: (1) all dairy products have background lipid 2,3,7,8-TCDD levels equivalent to those found in milk and half-and-half, i.e., about 55 ppq (whole dairy food levels were estimated using percent fat in each food); (2) levels averaging 35 ppq in beef tissue are present in all meat products; (3) ocean fish with tissue levels equal to half of the detection limit (about 0.5 ppt) are the sole fish source in the diet; (4) average food consumption figures (total-sample-basis) available from nationally representative data bases were used for frequency of eating (Market Research Corporation of America's (MRCA) Menu Census VI (1977-78)) and for serving sizes (U.S. Department of Agriculture's 1977-78 National Food Consumption Survey). FDA's estimates of 2,3,7,8-

Table 5-1. Predicted Average Daily Intake of 2,3,7,8-TCDD by the General Population of the United States

Media	Predicted media concentration[a]	Media intake (person/day)	Daily intake of 2,3,7,8-TCDD (pg/day)	Percent of daily intake
Inhalation	0.02 (pg/m^3)	20 (m^3)	0.4	1.1
Water	0.003 (pg/l)	1.33 l[b]	0.004	0.01
Soil ingestion	0.96 (ng/kg)	20 mg	0.02	0.05
Food				
Produce	0.06 (ng/kg)	20 g[b]	1.2	3.4
Milk and dairy products	0.03 (ng/kg)	266 g[b]	8.0	23.0
Beef	0.20 (ng/kg)	90 g[b]	18.0	51.7
Fish	0.38 (ng/kg)	18 g[b]	6.7	19.3
Eggs	0.01 (ng/kg)	25 g[b]	0.5	1.4
TOTAL			34.8	100

Source: Travis and Hattemer-Frey (1991)

[a] Values predicted by the Fugacity Food Chain model.
[b] Inferred consumption rate calculated by dividing reported daily intake (column 4) by predicted concentration (column 2).

TCDD intake were derived by multiplying the food dioxin levels by the average amounts of food consumed per day. The results of its assessment, summarized in Table 5-2, indicate an average daily exposure of 15.9 pg/day of 2,3,7,8-TCDD of which 4 percent are due to dairy and milk products, 41 percent are due to meats, and 54 percent are due to ocean fish.

Theelen (1991), of the Netherlands National Institute of Public Health and Environmental Protection, estimated the average daily intake of 2,3,7,8-TCDD and total dioxin TEQ by residents of the Netherlands for various possible routes of exposure. The results, summarized in Table 5-3, indicate an average intake of 20 pg/day of 2,3,7,8-TCDD and 115 pg/day of total TEQ from food and 0.08 pg/day (2,3,7,8-TCDD) and 3.2 pg/day (TEQ) from combined direct air and soil exposure. Milk and dairy products make up about one-third of the total daily exposure. Animal fat in meat, poultry, and fish (i.e., fish oil) also contribute about one-third. Fish consumption represents 18.5 percent of total daily exposure. In a later study, Theelen et al. (1993) reported a median daily intake for adults of 1 pg TEQ/kg body weight, and a 95th percentile rate of 2 pg TEQ/kg body weight. These values were based on CDD/F residue levels in food products and food consumption survey data.

Gilman and Newhook (1991), of the Canadian Department of National Health and Welfare and the Ontario Ministry of the Environment, respectively, estimated an average lifetime daily intake of 140 to 290 pg of TEQ for the typical Canadian. Their results, summarized in Table 5-4, indicate that between 94 and 96 percent of the estimated intake are from food sources. No breakdown of intake by food type is provided in the report.

As reported in Section 4.6.1, CDD/Fs can migrate from bleached paper packaging and paper food-contact articles to foods. Some investigators have included this pathway in estimates of background exposure. U.S. EPA (1990a) estimated that TEQ intake due to leaching from paper products into food from paper packaging was in the range of 5.5 to 12.7 pg/d. Henry et al. (1992) estimated that daily intake of 2,3,7,8-TCDD due to migration from paper to food could amount to 12 pg/d, almost as much as the daily intake from unaffected food of 16 pg/d. (See Table 5-2.) As shown in Table 5-3, Theelen (1991) estimated that out of a total of about 120 pg of TEQ/d, 9 pg of TEQ/d could be due to migration from paper. These estimates are based on levels in paper before recent changes in industry practices that are expected to substantially reduce dioxin levels in paper. As

Table 5-2. Predicted Average Daily Intake of 2,3,7,8-TCDD from Foods by the General Population of the United States

Media	2,3,7,8-TCDD concentration in food (ng/kg)	Food intake (g/person/day)	Daily intake of 2,3,7,8-TCDD (pg/day)	Percent of daily intake
Milk	0.0018	108.9	0.20	1.2
Cream	0.0072	2.0	0.01	<0.1
Sour cream	0.010	0.7	0.01	<0.1
Cheese	0.016	19.4	0.31	1.9
Ice cream	0.0055	7.5	0.04	0.3
Butter	0.044	2.6	0.11	0.7
Cottage cheese	0.0021	5.5	0.01	<0.1
Meats	0.035	187	6.55	41.2
Ocean fish	0.500	17.2	8.6	54.1
Coffee	0.0001	363.6	0.04	0.3
Orange juice	0.0002	33.5	0.01	<0.1
TOTAL			15.9	100

Source: Henry et al. (1992)

Table 5-3. Daily Exposure to 2,3,7,8-TCDD and TEQ from Air, Soil, Food, and Nonfood in the Netherlands

Media	Media Intake (g/person/day)	Daily Intake of 2,3,7,8-TCDD (pg/day)	Daily Intake of TEQ (pg/day)
Air inhaled	20 m^3	0.05	2
Air ingested (particulates)	[a]	0.025	1
Soil dermal	[b]	0.004	0.15
Soil ingested	150 mg	0.003	0.10
Uptake from air and soil		0.08	3.2
Leafy vegetables	27. g	0.2-2	1.8-7
Pork	15. g fat	0.45	4.2
Beef	5. g fat	3	13
Chicken and eggs	2.5 g fat	0.6	4.8
Milk	8. g fat	3.2	17
Cheese, butter	12.5 g fat	5	26
Sea fish	0.4 g fat	2	14
Fresh water fish	0.4 g fat	4	10
Fish oil	5.5 g	1.1	7.2
Vegetable oil	40. g	NDA	14
Intake from food		19.5-21.3	112-117
Intake from paper food packaging		NDA	9.1
TOTAL INTAKE		19.6-21.4	121-126

[a] Intake rate could not be determined from Theelen (1991).

[b] Assumes exposure of 2,000 cm^2 of skin to 1 mg of soil/cm^2. Soil concentrations assumed to be 7,000 mg TEQ/kg and 175 mg of 2,3,7,8-TCDD/kg. Dermal absorption of 1 percent assumed.

NDA = No data available.

Source: Theelen (1991).

Table 5-4. Estimated Lifetime Average Daily Exposure of Canadians to Dioxin TEQ

Media	Daily Intake of Dioxin[a] (TEQ) (pg/day)		
	Adult A[b]	Adult B[c]	Adult C[d]
Food	132 - 282	291 - 441	132 - 282
Air	3.5	3.5	12
Soil	1.75 - 1.90	1.75 - 1.90	1.75 - 1.90
Water	<0.7 - 3.5	<0.7 - 3.5	<0.7 - 3.5
Consumer Products	<0.7	<0.7	<0.7
Total Estimated Lifetime Intake[e]	140 - 290	300 - 450	150 - 300

Source: Gilman and Newhook (1991).

[a] These estimates represent the lifetime average daily intake calculated by dividing the total estimated intakes for each life stage (i.e., adult, child, infant, neonate) by the 70-year exposure period. The estimates in this table are based on the upper range of average national values and conservative assumptions that overestimate rather than underestimate exposures. These estimates are only approximations and not absolute values.

[b] Adult A is an average 70-kg adult consuming average amounts of air (20 m^3/day), water (1 liter/day), and soil (20 mg/day). Food intakes based on Nutrition Canada 1977 survey.

[c] Adult B is similar to Adult A except that consumption of fish contaminated with CDDs and CDFs is in excess of current Canadian guidelines.

[d] Adult C is similar to Adult A except that he/she lives in close proximity to an incineration/combustion source.

[e] These estimates have been rounded off because of the uncertainty in the data.

discussed in Section 4.6.1, these reductions are expected to have significantly lowered the CDD/CDF levels currently found in food due to any leaching of dioxin-like compounds from paper.

5.3. UPDATED ASSESSMENT OF BACKGROUND EXPOSURES

Background exposures to CDD/CDFs in North America were estimated using (1) the TEQ data on arithmetic mean levels in environmental media and food from Table 4-11, (2) the standard contact rates for ingestion of soil, water, and food and inhalation of ambient air, and (3) the appropriate unit conversion factors. The estimated exposures and assumptions made concerning ingestion or contact rates are presented in Table 5-5.

The background exposures reported here were estimated using standard intake rates representative of the general population. They do not account for individuals with higher consumption rates of a specific food group (e.g., subsistence fishermen, nursing infants, and subsistence farmers--these are discussed in Section 5.5). The estimates reported here are assumed to represent typical (i.e., "central tendency") U.S. background exposures, and do not account for these types of variations in the population as a result of differences in intake rates of the various food groups. The fish concentration used to estimate background exposures, represents the average value found in fish from fresh and estuarine waters (see Section 4.5). Correspondingly, the ingestion rate used here reflects the per capita average ingestion rate of fresh/estuarine fish (U.S. EPA, 1989). Many individuals are likely to have higher ingestion rates of marine fish. However, the limited data on marine species indicates that the dioxin levels may be one to two orders of magnitude lower than fresh/estuarine water fish (also see Section 4.5).

The contact rates for ingestion of fish, soil, and water, and inhalation were derived from the Exposure Factors Handbook (U.S.EPA, 1989). For food products such as milk, dairy, eggs, beef, pork, and poultry, a different approach was taken because there is some evidence that consumption rates have changed since the data for the Exposure Factors Handbook were collected. Contact rates for these food groups were derived from commodity disappearance data from the United States Department of Agricultures's (USDA) report on Food Consumption, Prices, and Expenditures between 1970 and 1992 (USDA, 1993), and intake data from USDA's Nationwide Food Consumption Survey (NFCS) (USDA, 1992). The average of USDA disappearance and NFCS intake rates were

Table 5-5. Estimated Background Exposures in the United States

Media	North America				
	Conc. TEQ[a]	Contact rate[b]	Daily intake[c] mg/day	Daily intake pg/day	% of total
Soil ingestion	8.0 ppt	100 mg/day	8.0×10^{-10}	0.8	0.7
Fish ingestion	1.2 ppt	6.5 g/day	7.8×10^{-9}	7.8	6.6
Inhalation	0.095 pg/m^3	23 m^3/day	2.2×10^{-9}	2.2	1.8
Water ingestion	0.0056 ppq	1.4 L/day	7.8×10^{-12}	0.008	0.01
Milk ingestion	0.07[d] ppt	251 g/day	1.8×10^{-8}	17.6	14.8
Dairy ingestion	0.36 ppt	67 g/day	2.4×10^{-8}	24.1	20.3
Eggs ingestion	0.14 ppt	29 g/day	4.1×10^{-9}	4.1	3.4
Beef ingestion	0.48 ppt	77 g/day	3.7×10^{-8}	37.0	31.2
Pork ingestion	0.26 ppt	47 g/day	1.2×10^{-8}	12.2	10.3
Poultry ingestion	0.19 ppt	68 g/day	1.3×10^{-8}	12.9	10.9
	Total		1.19×10^{-7}	119	100

Footnotes: NA = Not applicable, NDA = No Data Available.

[a] Values from Table 4-10.

[b] Values for soil ingestion, fish ingestion, inhalation, and water ingestion from Exposure Factors Handbook (USEPA, 1989) (fish ingestion rate represents average per capita non-marine fish consumption rate). All other contact rates are based on data from USDA (1992) and USDA (1993).

[c] Daily intake = Contact rate x Conc. TEQ x Unit Conversion (soil unit conversion = 10^{-12}, all other media unit conversion = 10^{-9}).

[d] Value was calculated from data in U.S., EPA (1991a).

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used in this study to represent typical contact rates in the United States. USDA (1993) estimated per capita consumption rates using disappearance data (i.e., the quantity of marketable food commodities utilized in the United States over a specified time period) divided by the total population. Consumption rates were calculated for several commodities including meats, eggs, milk and dairy products. For meats, the boneless equivalent quantity was calculated by adjusting the carcass weight based on the amount of fat and bone removed at different market levels. USDA (1992) reported one-day NFCS intake data for several meat categories. These included: beef; pork; poultry; frankfurters, sausages, and luncheon meats; fish and shellfish; and mixtures containing meat, poultry, and fish. Total intake rates for beef, pork, and poultry were estimated by assuming that the rate of consumption of these meats in (1) frankfurters, sausages, and luncheon meats, and (2) meat mixtures was proportional to the intake of these meats on an individual basis. Thus, the intake in these categories was apportioned among the meat groups. In general, intake rates based on NFCS data are lower than those based on USDA disappearance data. NFCS data are believed to underestimate consumption for the general population because they may not adequately account for consumption of foods contained in mixtures (i.e., the intake rate for eggs may include eggs eaten separately or as a main ingredient in a dish, but may not be counted if they are an ingredient in a cake). Additional uncertainty is associated with the use of data for only one day during the Spring of 1988 and the use of survey data based on recall. In contrast to NFCS data, disappearance data may overestimate per capita consumption because they are based on the quantity of marketable commodity utilized, divided by the total population. Disappearance data do not account for losses from the food supply from waste or from the production of items not intended for human consumption (i.e., pet foods). Thus, the average of USDA disappearance and NFCS intake rates were believed to be representative of typical contact rates in the United States.

Background exposure levels are also presented for Germany based on data from Fürst et al. (1990; 1991). The total background TEQ exposure shown in Table 5-5 is 119 pg/day for North America. Based on Fürst et al. (1990; 1991), the estimated total TEQ background exposure for Germany is 79 pg/day (Table 5-6). However, it should be noted that the estimated background level for the United States and Germany are based on limited data, and exposure to all food groups was not considered. Also, the addition of

Table 5-6. Background Exposures via Consumption of German Food

Food	TEQ[a] concentration (fat basis)	Intake Rate[b] g fat/day	TCDD - Equivalent[a] (pg/day)
Cow's milk	1.35	6.0	8.1
Cheese	0.98	5.2	5.1
Butter	0.66	12	7.9
Beef	1.69	10	16.9
Veal	3.22	0.1	0.3
Pork	<0.4	14	5.6
Chicken	1.41	1	1.4
Canned meat	1.29	2	2.6
Lard	0.47	1.5	0.7
Salad oil	<0.4	5	1
Margarine	<0.4	14	2.8
Fish and Fish Products Fresh water fish Salt water fish Fish oil Cod liver oil	 13.25 16.82 2.64 13.31	1.8	27
Total TEQ			**79.4**

[a] Milk data based on Fürst et al. 1991; other data based on Fürst et al. 1990.
[b] Based on data reported by Fürst et al. 1990.

TEQs for multiple pathways presumes that individuals are exposed by all pathways, and assumes that the fraction absorbed into the body is the same for all pathways. The following sections present observations about CDD/CDF exposures in North America, comparisons between exposure estimates from this and previous studies, and comparisons between North American and European exposures to CDD/CDFs.

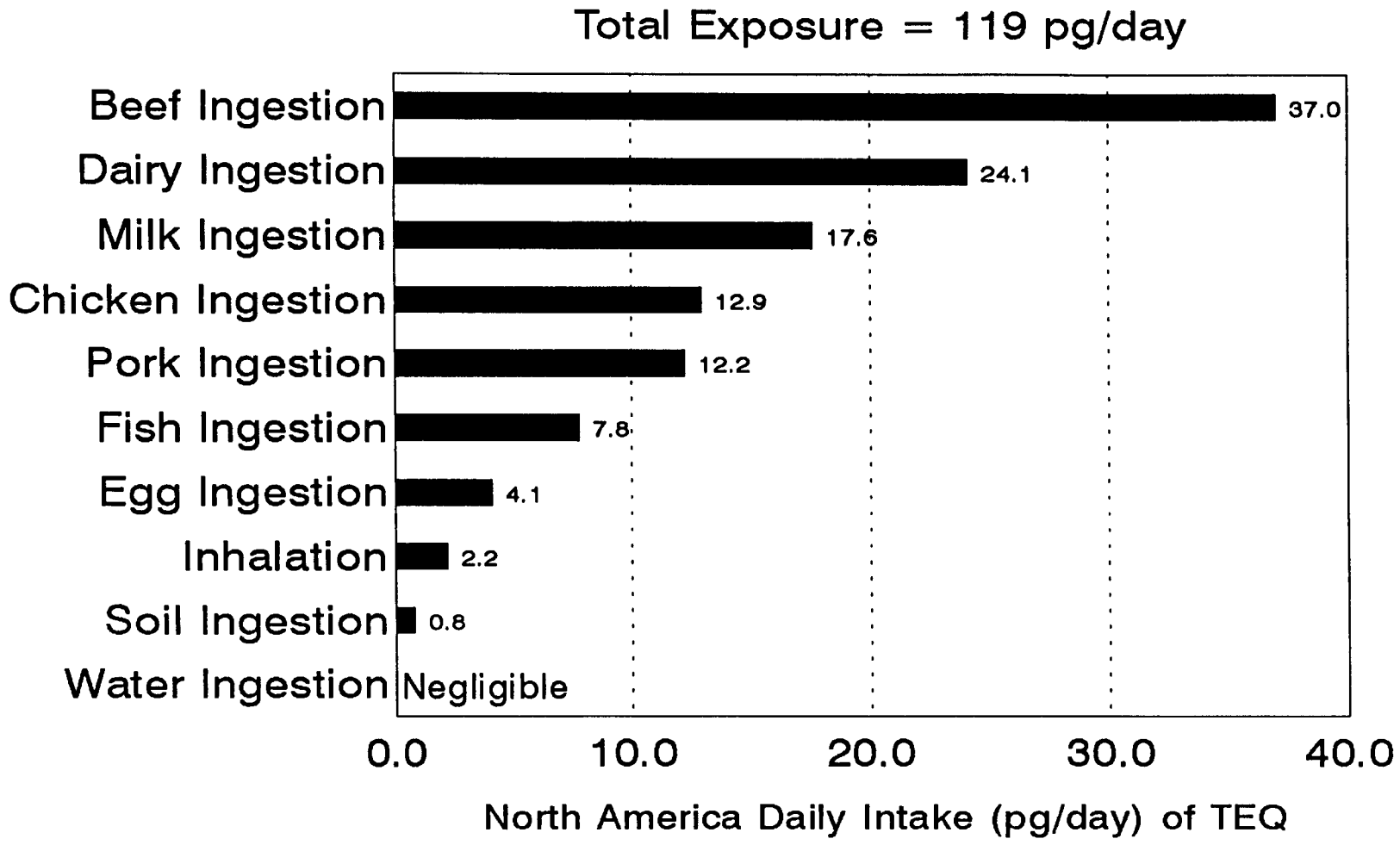
5.3.1. North American Exposures

Based on the data collected for this study, the total background CDD/CDF TEQ exposure for North America was estimated to be 119 pg/day, for all media combined. Exposure to 2,3,7,8-TCDD accounts for approximately 10.5 percent (12.0 pg/day) of the total TEQ exposure. Estimated exposures based on total CDD/CDF TEQs from the various exposure pathways are presented in Figure 5-1. The highest exposures were estimated to occur via ingestion of CDD/CDFs in beef (37 pg/day) which accounted for over 30 percent of the total TEQ exposure. The ingestion of foods accounted for over 97 percent of the total TEQ exposure. Exposure to CDD/CDFs via ingestion of water appears to be very low. Exposure via inhalation and soil ingestion are 2.2 and 0.8 pg/day, respectively. These exposures account for approximately 2.0 percent and <1.0 percent of the total CDD/CDF TEQ exposure in North America.

5.3.2. Comparison of Previous North American Studies to This Study

Previous studies of CDD/CDF exposures in North America were presented in Section 5.2 of this report. These studies reported CDD/CDF exposures based on the most toxic congener, 2,3,7,8-TCDD, and not on the total TEQ value for all congeners combined. For the purposes of comparison, mean background levels of 2,3,7,8-TCDD in North America from this assessment were used to calculate exposure via various pathways. Background exposures were calculated using background environmental levels of 2,3,7,8-TCDD, standard contact rates, and appropriate unit conversion factors, as described previously. Total 2,3,7,8-TCDD exposure for all pathways combined was 12.0 pg/day for the current assessment compared to 15.9 and 34.8 pg/day for the two previous studies of 2,3,7,8-TCDD exposure in North America (Henry et al., 1992; and Travis and Hattemer-Frey, 1991). Figure 5-2 depicts the comparisons of the percent contribution of various exposure pathways to total exposure to 2,3,7,8-TCDD for the current assessment and for

Figure 5-1 Background TEQ Exposure for North America by Pathway



Note: Only two congeners available for water; milk ingestion based on data reported by EPA(1991b). For a discussion of the uncertainty and variability associated with the media values and contact rates used to calculate these exposures, see Figure 4-1 and Sections 4.9 and 5.3.

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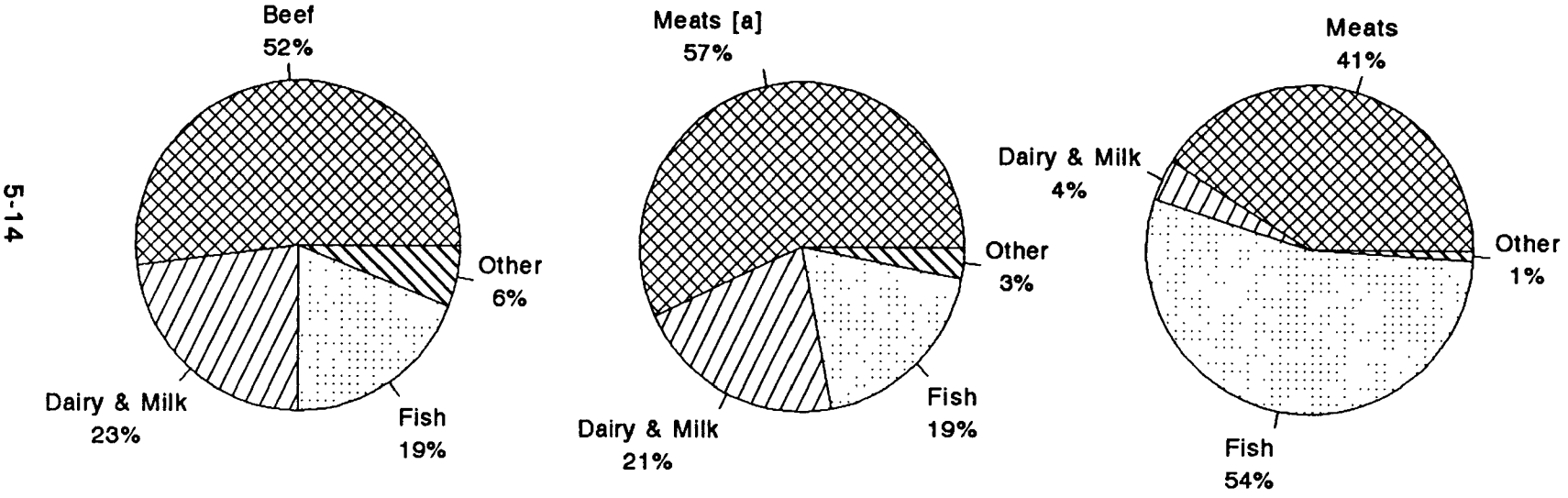
Figure 5-2 Percent Contribution of Various Media to 2,3,7,8-TCDD Exposure in North America



35 pg/day
Source: Travis & Hattemer-Frey, 1991

12.0 pg/day
Source: This Assessment

15.9 pg/day
Source: Henry et al, 1992

[a] Beef, Chicken, and Pork

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previous North American studies. Figure 5-2 indicates that exposure via ingestion of meats accounted for a large portion of the exposure in all three studies. However, fish accounted for a higher percentage, and dairy products accounted for a lower percentage of the total 2,3,7,8-TCDD exposure in the Henry et al. (1992) study than in the Travis and Hattemer-Frey (1991) study and the current assessment. These differences reflect differences in assumptions for food ingestion rates as well as in TCDD levels. All three studies indicate that beef, dairy products, and fish comprise over 94 percent of the total exposure. Because of the data base weaknesses noted earlier, it is not known if these differences can be considered significant.

5.3.3. Comparison of Previous European Studies to this Study

European CDD/CDF exposure studies may also be compared to the exposures estimated in U.S. reports and in the current assessment. Comparisons may be made based on the 2,3,7,8-TCDD congener or on total TEQ exposures (Table 5-7). Exposures to 2,3,7,8-TCDD in North America range from 12.0 pg/day to 34.8 pg/day based on the current assessment and two other U.S. studies. These values are comparable to the 2,3,7,8-TCDD exposures reported in Germany and the Netherlands by Fürst et al. (1991) and Theelen (1991). Fürst et al. (1991) reported an estimated 2,3,7,8-TCDD exposure of 25 pg/day based on ingestion of dairy products, meat, and fish; Theelen (1991) reported an estimate of 20 pg/day based on dairy, meat, poultry, and fish intake. Total CDD/F TEQ background exposure estimates for North America range from 119 pg/day for the current assessment to 140 to 290 pg/day based on Gilman and Newhook's (1991) Canadian study. For Europe, total TEQ exposure estimates range from 79 pg/day based on Fürst et al. (1990) to 158 pg/day based on Fürst et al. (1991). Figure 5-3 depicts the contributions of various exposure pathways to total background TEQ exposures for North America, Germany, and the Netherlands based on data from the current assessment, Fürst et al. (1990) and Theelen (1991). For all three geographic regions, over 90 percent of the exposures were attributed to ingestion of CDD/Fs in foods.

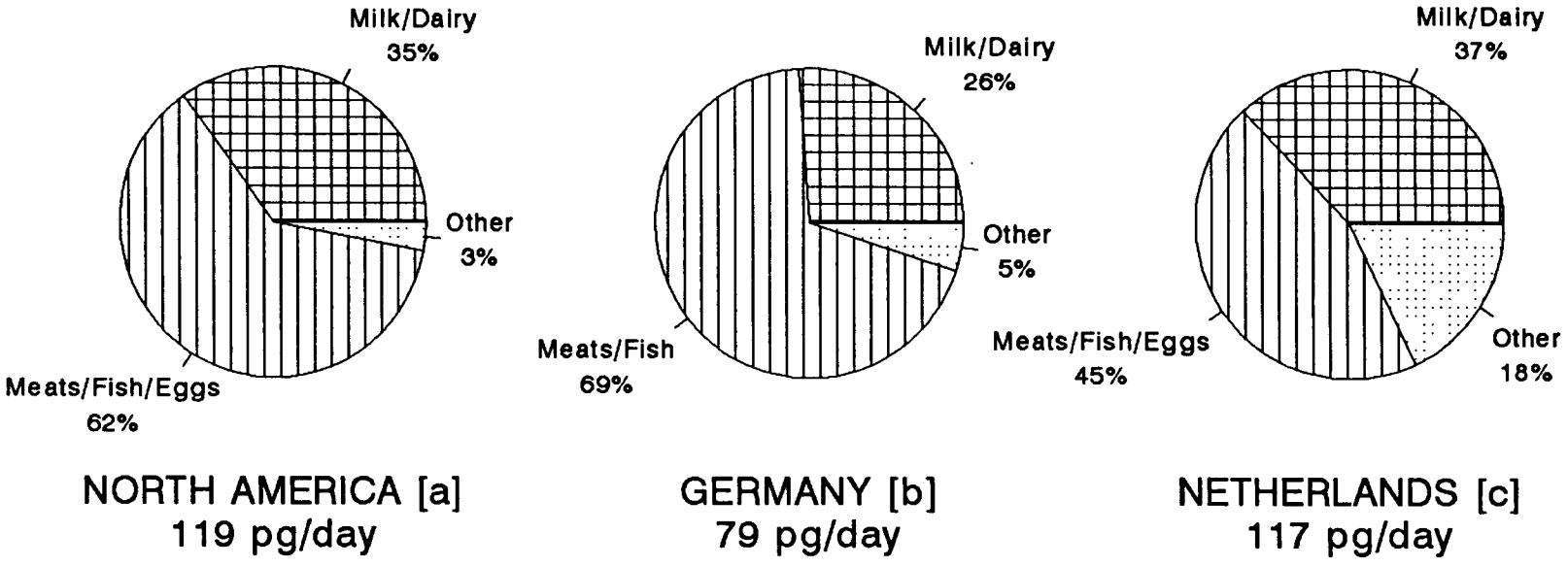
Based on the data presented in Figure 5-3, it is reasonable to expect that the CDD/CDF body burden in vegetarians would be lower than the body burden in non-vegetarians because vegetarians avoid the consumption of meat and fish and their derivative products. Welge et al. (1993) tested this hypothesis by comparing the

Table 5-7. Comparisons of Predicted Average Daily Intake of 2,3,7,8-TCDD and Total CDD/CDF TEQs

Location	Daily Intake of 2,3,7,8-TCDD (pg/day)	Daily Total TEQ intake (pg/day)	Media
United States[a]	34.8	--	beef, milk, produce, fish, eggs, water, inhalation
United States[b]	15.9	--	dairy, meat, fish
North America[c]	12.0	119	dairy, eggs, meat, poultry, fish, inhalation, soil ingestion
Canada[d]		140-290	air, water, soil, food
Germany[e]		85 (79)	dairy, meats, fish
Germany[f]	25.0	158	dairy, meat, fish
Netherlands[g]	20.0	121-126	dairy, meat, poultry, fish

a Travis and Hattemer-Frey (1991)
b Henry et al. (1992)
c Current Assessment
d Gilman and Newhook (1991)
e Fürst et al. (1990); value in parentheses is the corrected TEQ value based on the milk data from Fürst et al. (1991)
f Fürst et al. (1991)
g Theelen (1991)

Figure 5-3 Comparison of Background TEQ Exposures



[a] Current Assessment. See Table 5-5. Other category includes inhalation (1.8%), soil ingestion (0.7%), and water (0.01%)

[b] Based on Furst et al. (1990,1991). See Table 5-6. Other Category includes salad oil (1.3%) and margarine (3.5%)

[c] Based on Theelen (1991). See Table 5-3. Other refers to inhalation (2.5%), soil ingestion (0.2%), leafy vegetables (3.4%), and vegetable oil (11.9%)

Note: Percentages were rounded to the nearest whole number

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CDD/CDF levels in the blood of 24 German vegetarians with the blood levels of 24 non-vegetarians, matched for age, sex, body weight, and height. With the exception of two individuals, all vegetarians had practiced a diet without meat and fish for at least 3 years.

The CDD/CDF levels in the vegetarian group ranged from 14.64 to 52.85 pg TEQ/g (lipid basis) with a mean of 32.60 pg TEQ/g. In the non-vegetarian group, the CDD/CDF levels ranged from 14.26 to 97.98 pg TEQ/g (lipid basis) with a mean of 34.32 pg TEQ/g. There was no significant difference (α = 0.05) between the vegetarian and non-vegetarian group in the mean levels of any of the 2,3,7,8-substituted congeners, in the total CDD levels, in the total CDF levels, in the total CDD/CDF levels, or in the total TEQ levels (each on a lipid and on a whole weight basis). Welge et al. (1993) suggested several reasons why no differences were found. First, all tested vegetarians had at one time been non-vegetarians. The higher levels of exposure during this non-vegetarian period coupled with the long biological half-life of CDD/CDFs may be responsible for the apparent similarity in body burdens using blood as the measure of body burden. Second, the vegetarians may have a higher level of consumption of dairy products than the non-vegatarians and thus have a similar CDD/CDF exposure even without consumption of fish and meat.

5.4. ASSESSMENT OF BACKGROUND EXPOSURES ON THE BASIS OF BODY BURDEN DATA

5.4.1. Human Adipose Tissue and Blood Data

Examination of body burden data provides another, potentially more accurate, way to estimate exposures of humans to CDD/CDFs. However, these data may not represent only background exposure to CDD/CDFs as defined here because the sampled individuals may have lived in areas where dioxin sources were present. The most extensive U.S. study of CDD/F body burdens is the National Human Adipose Tissue Survey (NHATS) (EPA, 1991b). This survey analyzed for CDD/Fs in 48 human tissue samples that were composited from 865 samples. Each composite contained an average of 18 specimens. These samples were collected during 1987 from autopsied cadavers and surgical patients. The sample compositing prevents use of these data to examine the distribution of CDD/F levels in tissue among individuals. However, it did allow conclusions in the following areas:

- National Averages - The national averages for all TEQ congeners were estimated as listed in Table 5-8. Nondetects were treated as half the detection limit for averaging purposes. As shown in this table, all congeners except some of the CDFs had a very low frequency of nondetects. Thus, the overall TEQ estimate is not sensitive to how nondetects were treated in the averaging.

- Age Effects - Tissue concentrations of CDD/Fs were found to increase with age.

- Geographic Effects - In general the average CDD/F tissue concentrations appeared fairly uniform geographically. Only one TEQ congener was found to have a significant difference among geographic regions of the country. This compound, 2,3,4,7,8-PeCDF, was found at the lowest level in the West (4.49 pg/g) and the highest in the Northeast (13.7 pg/g).

- Race Effects - No significant difference in CDD/F tissue concentrations was found on the basis of race.

- Sex Effects - No significant difference in CDD/F tissue concentrations was found between males and females.

- Temporal Trends - The 1987 survey showed decreases in tissue concentrations relative to the 1982 survey for all congeners. However, it is not known whether these declines were due to improvements in the analytical methods or actual reductions in body burden levels. The percent reductions among individual congeners varied from 9 percent to 96 percent.

New information on levels of dioxin-like compounds in human tissue/blood has recently been published (Patterson et al., 1994). Human adipose from 28 individuals was collected. The individuals studied were ones that died suddenly in the Atlanta area during 1984 or 1986. Their ages ranged from 19 to 78 yr and averaged 49 yr. The tissue data are summarized in Table 5-9. This table shows that the mean PCB levels generally exceeded the mean 2,3,7,8-TCDD level and PCB-126 exceeded the 2,3,7,8-TCDD level by over an order of magnitude. The mean TEQ levels for these coplanar PCBs summed to about 17 ppt (using the toxic equivalency factors proposed by Safe, 1990). A complete CDD/F congener analysis was conducted on tissues of five of the individuals, resulting in an average of 25 ppt on a TEQ basis. These tissue samples were also analyzed for PCBs 77, 126 and 169. The TEQ levels for these coplanar PCBs summed to 8.2 ppt (using the toxic equivalency factors proposed by Safe, 1990). Thus, the PCBs contributed 24% of the total TEQs. Patterson et al. (1994) also studied serum collected by the CDC blood

Table 5-8. NHATS Mean Adipose Tissue Data

Congener	Congener Concentration (pg/g)	TEQ Concentration (pg/g)	Percent Detected[a]
2,3,7,8-TCDD	5.38	5.38	97
2,3,7,8-PeCDD	10.7	5.35	97
2,3,7,8-HxCDD	86.8	8.68	97
2,3,7,8-HpCDD	110	1.1	100
OCDD	724	0.72	100
2,3,7,8-TCDF	1.88	0.19	100
1,2,3,7,8-PeCDF	0.31	0.016	14
2,3,4,7,8-PeCDF	9.7	4.85	95
2,3,7,8-HxCDF	14.2	1.42	2 to 92
2,3,7,8-HpCDF	16	0.16	4 to 89
OCDF	2.28	0.002	30
TOTAL		27.9	

[a] Based on analysis of 48 samples composited from 865 samples

Source: U.S. EPA (1990b)

Table 5-9. Human Adipose Tissue Data

Chemical	Range (ppt)	Mean (ppt)
2,3,7,8-TCDD	1.6 to 38	10.4
PCB 77	Nondetect to 27.9	11.7
PCB 126	14.6 to 371	135
PCB 169	29.5 to 174	69
PCB 81	1.5 to 21.3	10.5

Source: Patterson et al. (1994)

bank in Atlanta during 1982, 1988 and 1989. These samples were pooled from over 200 donors. The average levels for 2,3,7,8-TCDD and PCBs are summarized in Table 5-10. The serum data appears to indicate a decrease in exposure to PCBs from 1982 to 1988/1989. In general, the Patterson et al. (1994) data suggests that the coplanar PCBs can contribute significantly to body burdens of dioxin-like compounds. The data suggest that the coplanar PCBs can increase the total background body burden to over 40 ppt of TEQ. This conclusion is uncertain because the people studied by Patterson et al. (1994) may not be representative of the overall U.S. population, and the toxic equivalency factors proposed by Safe (1990) have been acknowledged to be conservative.

Schecter et al. (1993) reported on the comparison of the congener-specific measurement of CDDs, CDFs, and dioxin-like PCBs in whole blood samples of four individuals with known exposures to that of the general population. In this comparison, the analytical results of separate 450 ml blood samples collected from 50 Michigan residents, and a pooled blood sample from 5 donors at a blood bank in Missouri were used as the control group. Two of the exposed individuals were pulp and paper plant workers with potential exposure to dioxins, and the other two were Michigan residents who had elevated blood PCB levels from consuming contaminated fish. It was found that the control group and the pulp and paper mill workers who had no known exposures to PCBs had relatively high levels of coplanar, mono-ortho and di-ortho PCBs in their whole blood. On average, the Michigan and Missouri control samples showed a mean CDD/CDF TEQ concentration of 27 ppt and 25 ppt, respectively. These same samples showed PCB-TEQ (based on Safe, 1990) mean concentrations of 66 ppt for the Michigan controls, and 45 ppt for Missouri controls.

Levels of these compounds found in human tissue/blood appear similar in Europe and North America. Schecter (1991) compared levels of dioxin-like compounds found in blood among people from U.S. pooled samples from 100 subjects and Germany (85 subjects). Although mean levels of individual congeners differed by as much as a factor of two between the two populations, the total TEQ averaged 42 ppt in the German subjects and was 41 ppt in the pooled U.S. samples. In a later report, Schecter et al. (1994a) reported human blood levels for the general population from various countries. These data are presented in Table 5-11. Schecter (1991) reports adipose tissue levels in various countries, as summarized in Table 5-12. The adipose tissue data show more variation

Table 5-10. Mean Levels in Human Serum (ppt)

Chemical	1988	1989	1982
2,3,7,8-TCDD	0.159	0.0165	Not Measured
PCB 77	0.481	0.251	1.38
PCB 126	0.183	0.135	0.281
PCB 169	0.151	0.192	0.282
Total PCBs	3,100	Not Measured	Not Measured

Source: Patterson et al. (1994)

Table 5-11. CDD/CDF Levels in Human Blood from Various Countries

Country	Mean Blood Level (ppt of TEQ, lipid)	Number of Samples
USA	41	100
Germany	42	85
S. Vietnam (Ho Chi Minh)	28	50
S. Vietnam (Dong Nai)	49	33
N. Vietnam (Hanoi)	12	32
Guam	32	10
Soviet Union (St. Petersburg)	17	50
Siberia (Baikalsk)	18	8

Source: Schecter et al. (1994a)

Table 5-12. Dioxin Levels in Human Adipose Tissues from Various Countries

Country	Mean Tissue Level (ppt of TEQ)	Number of Samples
USA	24	15
Germany	69	4
China	18	7
Japan	38	6
Canada	36	46
S. Vietnam	30	41
N. Vietnam	4	26

Source: Schecter (1991)

between countries but also involved much fewer samples, reducing confidence in the accuracy of the mean. Beck et al. (1994) reported on levels of CDD/CDFs in adipose tissue from 20 males (mean age-50 years) from Germany. TEQs ranged from 18 ppt to 122 ppt with a mean of 56 ppt, on a fat weight basis. Beck et al. (1994) also observed that CDD/CDF levels were found to be dependent on the age of the individual. 2,3,7,8-TCDD was found to increase at a rate of 0.12 pg/g fat per year, and TEQs increased at a rate of 0.77 pg/g fat per year. Beck et al. (1994a) also reported on CDD/CDF levels in various organs of the body. In comparison to adipose tissue, the concentrations of CDD/CDFs in brain and placental tissue were found to be low. Accumulation of CDD/CDFs was not found to occur in the thymus, spleen, and liver, based on whole weight concentrations. Schecter et al. (1994a) also reported on TEQ levels in organs of two autopsy patients from New York. The highest concentrations of CDD/CDFs were found in adipose tissue (28 ppt TEQ), adrenal tissue (14 ppt TEQ), and liver (12 ppt TEQ), on a whole weight basis. Lower concentrations were observed in spleen (4.6 ppt TEQ), muscle (2.4 ppt TEQ), and kidney (0.8 ppt TEQ). Schecter et al. (1994b) reported PCB levels for these two autopsy potients. Total PCBs in adipose tissue were 280.7 ppb on a wet weight basis and 344.2 ppb on a lipid weight basis.

In Chapter 6, the level of 2,3,7,8-TCDD found in human adipose tissue is assumed to average about 5.0 to 6.7 ppt in the United States based on data from a variety of studies. These adipose tissue data were used to estimate the associated exposure levels using a simple pharmacokinetic model that back calculates the dose needed to achieve the observed adipose tissue levels under the assumption of steady state exposure/dose. This model requires an estimate of the elimination rate constant. Based on available data, this elimination rate constant was assumed to be about 5 to 7 years which yielded a background dose rate of about 10 to 31 pg/day. This estimate agrees very well with the background exposure estimates (to 2,3,7,8-TCDD only) of 35 pg/day by Travis and Hattemer-Frey (1991), 25 pg/day by Fürst et al. (1991) and 12 pg/day from this assessment, all derived using typical media levels and contact rates. Further discussion of body burden data and associated exposures is presented in Chapter 6. Chapter 6 presents biologically-based pharmacokinetic models to estimate body burden levels. Some less sophisticated approaches have also been presented in the literature. For example, Travis and Hattemer-Frey (1988) developed linear relationships between the bioaccumulation of

organic chemicals in human tissues and the octanol-water partition coefficients (K_{ow}) of the chemicals. The biotransfer factors (BTFs) that can be calculated using this relationship can be used to estimate adipose tissue and breast milk concentrations of organics. The BTF for human adipose tissue (B_f) is defined as the concentration of an organic in adipose tissue (mg/kg) divided by the average daily intake of that organic (mg/day). The human breast milk BTF (B_m) is defined as the concentration of an organic in breast milk (mg/kg) divided by the average daily intake of that organic (mg/day). Adipose tissue and milk concentrations are assumed to be equilibrium concentrations resulting from long-term, consistent daily intake of an organic.

Measured tissue concentrations and either measured or estimated daily chemical intakes were used to estimate the BTFs (12 chemicals for B_f and 6 chemicals for B_m). Geometric mean regression analysis was used to ascertain the correlation between K_{ow} values and the calculated BTFs. The results of the analyses are as follows:

$$B_f = 3.2 \times 10\text{-}4\ K_{ow} \quad n = 12 \quad r = 0.98$$

$$B_m = 6.2 \times 10\text{-}4\ K_{ow} \quad n = 6 \quad r = 0.94$$

The high correlation coefficients demonstrate that the BTFs for human adipose tissue and breast milk are strongly, positively correlated with the octanol-water coefficient. While the data upon which these correlations are based are limited both in terms of number of chemicals and the extent of measured vs. estimated intakes, the results are consistent with results reported by Travis and Hattemer-Frey (1988) for beef and dairy cattle.

5.4.2. Dermal Exposure

Horstman and McLachlan (1994) measured CDD/F levels in human skin using an adhesive tape stripping method. Skin samples of the stratum corneum were collected from the backs of eight volunteers of varying age and sex. Two additional layers of increasing depth were collected from 5 people. All showed a decrease in CDD/F levels with depth. The concentration in the first layer ranged from 1,000 to 7,800 pg/g on a total CDD/F basis. The second layer was an average of 43 percent lower and the third layer was an average of 33 percent lower. OCDD was the dominant congener in all three layers. Also, non-2,3,7,8 substituted congeners were identified, congeners which are not normally present in human tissue.

In addition, samples of the epidermis and subcutis were analyzed. These analyses indicated that levels of the non-2,3,7,8 substituted congeners were much higher in the stratum corneum than in the epidermis and none were identified in the subcutis. The authors argue that because these congeners could not be transported from inside the body to the stratum corneum, the CDD/F in the stratum corneum must originate from external sources. Horstman and McLachlan (1994) hypothesized that textiles could be the source of skin contamination. Thirdy-five new textiles, primarily cotton products, were analyzed and found to have a total CDD/F level that was generally less than 50 ng/kg, but several colored T-shirts had high levels, with concentration up to 290,000 pg/g. The homolog patterns in the textiles were similar to the patterns found in the skin. Experiments were then conducted measuring the CDD/F levels in human skin before and after wearing T-shirts. Significant increases in CDD/F levels in the skin occurred after wearing the highly contaminated shirts for 1-2 weeks and significant decreases in CDD/F levels in the skin occurred after wearing the uncontaminated shirts for 1-2 weeks.

Thus, this work strongly suggests that dermal exposure to textiles may be contributing to background exposures to CDD/Fs. Horstman and McLachlan (1994) comment that although the levels of most CDD/F congeners in humans can be explained on the basis of diet, the origins of OCDD in humans is less clear. Since OCDD was found to be the dominant congener in textiles and skin, they speculate that the human body burden of this congener may result from dermal absorption. Horstman and McLachlan (1994) further discuss that human scale (stratum corneum) contributes to house dust and could lead to exposure via inhalation.

5.5. HIGHLY EXPOSED POPULATIONS

Certain groups of people may have higher exposures to the dioxin-like compounds than the general population. The following sections discuss higher exposures that result from dietary habits. Other population segments can be highly exposed due to occupational conditions or industrial accidents. For example, several epidemiological studies 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. These epidemiological studies are fully discussed in the Epidemiology Chapter of the Dioxin

Health Reassessment Document (EPA, 1994) and should be consulted if further details are desired.

5.5.1. Nursing Infants

Schecter et al. (1992) reports that a study of 42 U.S. women found an average of 16 ppt of TEQ (3.3 ppt of 2,3,7,8-TCDD) in the lipid portion of breast milk. A much larger study in Germany (n= 526) found an average of 29 ppt of TEQ in lipid portion of breast milk (Fürst et al., 1994). Bates et al. (1994) analyzed breast milk samples from 38 women in New Zealand and reported mean lipid-based TEQs of 16.5 ppt for urban women and 18.1 ppt for rural women. The age of the mother was found to be positively correlated with the concentration of CDD/CDFs in breast milk. Beck et al. (1994) reported a mean TEQ of 30 ppt in the milk fat based on 112 human milk samples from Germany. The congeners that contributed the most to the total TEQ were 2,3,4,7,8-PeCDF (35 percent), total HxCDD (22 percent), and 1,2,3,7,8-PeCDD (21 percent). Beck et al. (1994) observed that CDD/CDFs levels decreased with the number of children and the duration of breast feeding, but increased with the age of the mother. Beck et al. (1994) also compared the adipose tissue levels of breast-fed and bottle-fed infants who had died of sudden infant death syndrome. The breast-fed infants had higher tissue levels (5.4 to 22 pg/g fat; n=4) than the bottle-fed infants (2.1 to 4.4 pg/g fat; n=2).

The levels in human breast milk can be predicted on the basis of the estimated dioxin intake by the mother. Such procedures have been developed by Smith (1987) and Sullivan et al. (1991) and are also presented in Chapter 6. The approach by Smith assumes that the concentration in breast milk fat is the same as in maternal fat and can be calculated as:

$$C_{milk\ fat} = \frac{m\ h\ f_1}{0.693\ f_2} \qquad \text{(Eqn. 5-1)}$$

where,

$C_{milk\ fat}$ = concentration in maternal milk (pg/kg of milk fat)

m = average maternal intake of dioxin (pg/kg of body weight/day)

h = half-life of dioxin in adults (days)

f_1 = proportion of ingested dioxin that is stored in fat

f_2 = proportion of mother's weight that is fat (kg maternal fat/kg total body weight)

This steady-state model assumes that the contaminant levels in maternal fat remain constant. Though not described here, Smith (1987) also presents more complex approaches that account for changes in maternal fat levels during breast feeding. The model developed by Sullivan et al. (1991) is a variation of the models proposed by Smith (1987). The Sullivan model considers changes in maternal fat levels and predicts chemical concentrations in milk fat as a function of time after breast feeding begins. The model proposed by Smith assumes that infant fat concentration at birth is zero, whereas Sullivan assumes that the infant fat concentration at birth is equal to the mother's fat concentration.

As discussed in Chapter 6, the half-life of 2,3,7,8-TCDD in humans is estimated to be 5 to 7 years. For the purpose of this preliminary analysis, it is assumed that a 7-year half-life applies to all of the dioxin-like compounds. Smith (1987) suggests values of 0.9 for f_1 and 0.3 for f_2. Using these assumptions and a background exposure level of 1 to 3 pg of TEQ/kg-d (derived from diet analysis, see Section 5.3), the concentration in breast milk fat is predicted to be about 10 to 30 ppt of TEQ, which agrees well with the measured values.

Using the estimated dioxin concentration in breast milk, the dose to the infant can be estimated as follows:

$$ADD_{infant} = \frac{C_{milk\ fat}\ f_3\ f_4\ IR_{milk}\ ED}{BW_{infant}\ AT} \qquad \text{(Eqn. 5-2)}$$

where,

ADD_{infant} = Average daily dose to the infant (pg/kg/d)

IR_{milk} = Ingestion rate of breast milk (kg/d)

ED = Exposure duration (yr)

BW_{infant}	=	Body weight of infant (kg)
AT	=	Averaging time (yr)
f_3	=	Fraction of fat in breast milk
f_4	=	Fraction of ingested contaminant that is absorbed

This approach assumes that the contaminant concentration in milk represents the average over the breast feeding time period. If the dynamic models mentioned above are used, the dose can be estimated using an integration approach to account for the changes in concentration over time.

Smith (1987) reports that a study in Britain found that the breast milk ingestion rate for 7 to 8-month old infants ranged from 677 to 922 ml/d and that a study in Houston measured the mean production of lactating women to range from 723 to 751 g/d. Smith (1987) also reports that breast milk ingestion rates remain relatively constant over an infant's life, that the milk can be assumed to have a 4 percent fat content, and that 90 percent of the ingested contaminant are absorbed. The National Center for Health Statistics (1987) reports the following mean body weights for infants:

6-11 months:	9.1 kg
1 year:	11.3 kg
2 year:	13.3 kg

Using Equation 5.2 and assuming that an infant breast feeds for 1 year, has an average weight during this period of 10 kg, ingests 0.8 kg/d of breast milk, and that the dioxin concentration in milk fat is 20 ppt of TEQ, the ADD to the infant over this period (i.e., AT = 1 yr) is predicted to be about 60 pg of TEQ/kg-d. This value is much higher than the estimated range for background exposure to adults (i.e., 1-3 pg of TEQ/kg-d). However, if a 70 year averaging time is used, then the LADD (Lifetime Average Daily Dose) is estimated to be 0.8 pg of TEQ/kg-d, which is near the lower end of the adult background exposure range. On a mass basis, the cumulative dose to the infant under this scenario is about 210 ng compared to a lifetime background dose of about 1700 to 5100 ng (suggesting that 4 to 12 percent of the lifetime dose may occur as a result of breast feeding). Traditionally, EPA has used the LADD as the basis for evaluating cancer risk and

the ADD (i.e., the daily exposure per unit body weight occurring during an exposure event) as the more appropriate indicator of risk for noncancer endpoints. This issue is discussed further in Chapter 6 and in the companion document on dioxin health effects.

The simplified procedure described above contains a number of uncertainties. A tendency toward overestimates of the dose to the infant is caused by the assumption that reductions do not occur in maternal fat levels during breast feeding. Sullivan et al. (1991) estimates that the steady-state assumption may lead to overestimates of 20 percent. Uncertainty is also introduced by the assumption that the assumed half-life rate and partitioning factors apply to all the dioxin related compounds. Although these properties are likely to be similar among the various congeners, some variation is expected. It is unknown whether the net effect of these uncertainties would lead to over or under estimates of dose. However, the simple model appears to provide reasonable predictions of background levels found in breast milk and was judged adequate for purposes of a preliminary analysis. For detailed assessments, readers should consider using the more complex models and developing chemical-specific property estimates.

Travis and Hattemer-Frey (1988) presented an alternative approach to estimating breast milk contaminant levels. They proposed a biotransfer approach:

$$C_m = B_m I \qquad \text{(Eqn. 5-3)}$$

where:

C_m = contaminant concentration in breast milk (mg/kg)
B_m = biotransfer factor for breast milk (kg/d)
I = maternal intake of contaminant (mg/d)

They also argue that the biotransfer factor is primarily a function of the octanol-water partition coefficient (K_{ow}) and developed the following geometric mean regression:

$$B_m = 6.2 * 10^{-4} Kow \qquad \text{(Eqn. 5-4)}$$

This regression was derived from data on 6 lipophilic compounds (log K_{ow} range: 5.16 to 6.5), but did not include any dioxins or furans. Assuming a log K_{ow} of 6.6 for 2378-TCDD, a B_m of 3700 kg/d is predicted. Combing this value with a maternal intake of 10 pg/d (or 10^{-7} mg/d), a breast milk concentration of 37 ppt is predicted. This prediction is about 10 times higher than what has been measured in the U.S. Thus, this approach does not appear to work as well as the earlier approach suggested by Smith et al (1987).

5.5.2 Subsistence Fishers

The possibility of high exposure to dioxin as a result of fish consumption is most likely to occur in situations where individuals consume a large quantity of fish from one location where the dioxin level in the fish are elevated above background levels. Most people eat fish from multiple sources and even if large quantities are consumed they are not likely to have unusually high exposures. However, individuals who fish regularly for purposes of basic subsistence are likely to obtain their fish from one source and have the potential for elevated exposures. Such individuals may consume large quantities of fish. EPA (1989) presents studies that indicate that recreational anglers near large water bodies consume 30 g/day (as a mean) and 140 g/day (as an upper estimate). Wolfe and Walker (1987) found subsistence fish ingestion rates up to 300 g/day in a study conducted in Alaska.

Svensson et al. (1991) found elevated blood levels of CDDs and CDFs in high fish consumers living near the Baltic Sea in Sweden. Three groups were studied: nonconsumers (n=9), moderate consumers (n=9, 220 to 500 g/wk) and high consumers (n=11, 700-1750 g/wk). The high consumer group was composed of fishermen or workers in the fish industry who consumed primarily salmon (30 - 90 pg TEQ/g) and herring (8-18 pg TEQ/g) from the Baltic Sea. The TEQ blood level was found to average about 60 pg TEQ/g lipid among the high consumers and 20 pg TEQ/g lipid for the nonconsumers. This difference was particularly apparent for the PeCDFs.

Studies are underway to evaluate whether native Americans living on the Columbia River in Washington have high dixoin exposures as a result of fish consumption. These tribes consume large quantities of salmon from the river. A recent study (Columbia River Intertribal Fish Commission, 1993) suggests that these individuals have an average fish

consumption rate of 30 g/day and a 95th percentile rate of 170 g/day. Currently studies are underway to measure dioxin levels in fish from this region.

Dewailly et al. (1994) observed elevated levels of coplanar PCBs in the blood of fishermen on the north shore of the Gulf of the St. Lawrence River who consume large amounts of seafood. Of the 185 study samples, the 10 samples with the highest total PCB levels were analyzed for coplanar PCBs. Samples from Red Cross blood donors in Ontario served as controls. Coplanar PCB levels were 20 times higher among the 10 highly exposed fishermen than among the controls. Based on these results of the 10 highest samples, Dewailly et al. (1994) estimated that for the entire fishing population studied, coplanar PCB levels would be eight to ten times higher than the control group. Dewailly et al. (1994) also observed elevated levels of coplanar PCBs in the breast milk of Inuit women of Arctic Quebec. The principal source of protein for the Inuit people is fish and sea mammal consumption. Breast milk samples were collected from 109 Inuit women within the first three days after delivery and analyzed for di-ortho-coplanar PCBs during 1989 and 1990. Subsets of 35 and 40 randomly selected samples were analyzed for mono-ortho coplanar and non-ortho coplanar PCBs, respectively. Samples from 96 caucasian women from Quebec served as controls. The levels of non-ortho coplanar PCBs for Inuit women ranged from 24.7 to 220.9 ppt. These values were 3 to 7 times higher than those observed in the control group. For mono-ortho and di-ortho coplanar PCBS, the levels among the Inuit women were three to ten times higher than in the control group.

5.5.3. Subsistence Farmers

The possibility of high exposure to dioxin as a result of consuming meat and dairy products is most likely to occur in situations where individuals consume a large quantity of these foods from one location where the dioxin level is elevated above background levels. Most people eat meat and diary products from multiple sources and even if large quantities are consumed they are not likely to have unusually high exposures. However, individuals who raise their own livestock for purposes of basic subsistence have the potential for elevated exposures. No epidemiological studies were found in the literature that evaluated this issue. However, Volume III of this document presents methods for evaluating this type of exposure on a site-specific basis.

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6. PHARMACOKINETICS

6.1. INTRODUCTION

The pharmacokinetic profiles of CDDs and the CDFs are quite complex. A thorough analysis and understanding of these pharmacokinetic data would be very helpful in ensuring that exposure assessments for these compounds are reliable. In addition, such information would be useful in providing enhanced knowledge and understanding for the purposes of risk assessment. Previous drafts of this chapter included a discussion on bioavailability of CDD/Fs. Since this topic is only loosely related to pharmacokinetics, it was decided to move this discussion to an appendix and it now appears in Appendix C of this Volume.

Exposure to 2,3,7,8-TCDD and related compounds results in numerous species and tissue specific toxic and biological responses. Many, if not, all of these responses are mediated by a soluble intracellular protein, the aryl hydrocarbon (Ah) receptor, to which 2,3,7,8-TCDD binds with high affinity. After 2,3,7,8-TCDD and related compounds bind to this Ah receptor the complex undergoes a transformation process involving dissociation of hsp90. The transformed receptor complex is then able to bind with high affinity to a specific DNA sequence referred to as a dioxin responsive enhancer (DRE). The conserved nature of the DRE and Ah receptor is also indicated by the ability of transformed 2,3,7,8-TCDD: Ah receptor complexes from a wide variety of species to bind to the DRE. Studies also indicate a similarity in DNA recognition by Ah receptor from a variety of species suggestive of a functional role of this sequence in 2,3,7,8-TCDD responsiveness (Denison et al., 1991; Gasiewicz and Henry, 1991; Perdew and Hollenbeck, 1990; Andersen and Greenlee, 1991). Thus the definition of "disposition" may have to be extended to include suborgan or subcellular sites in order to more fully describe the congener, species, and train specific pharmacokinetics (dosimetry) of these compounds.

Pharmacokinetic analysis may be used in several ways to aid in the exposure and dose assessment of foreign chemicals. They may, for example, allow for predicting the time and profile of elimination of chemicals from the body. The redistribution of CDDs among the various tissues and organs, which may occur during elimination, can be

accounted for and tracked. Effects on disposition which may result from altered physiology, such as sudden weight loss or from lactation, can be incorporated and thus adequately considered in exposure and risk assessments. Lactation is known to be an efficient route for the transfer of many of these chemicals from mother to offspring (Nau et al., 1986; Bowman et al., 1989).

Pharmacokinetic analyses can be used to estimate background exposure levels from body burden data. They can also be used to estimate uptake rates from various food sources, elimination rates and times from the body, and to estimate tissues levels from blood and adipose tissue monitoring. In addition, with the appropriate data on several congeners, estimates can be made for other congeners about which less data are available.

The remainder of this chapter will cover areas of pharmacokinetics pertinent to exposure assessment. Background levels and daily uptake of 2,3,7,8-TCDD will be reviewed and discussed; a method for the calculation of uptake of other congeners from food will be outlined; use of a compartmental model to estimate daily uptake will be demonstrated; a method will be outlined and reviewed for determining internal tissue concentrations from monitored blood and/or adipose tissue; exposure through lactation will also be discussed.

6.2. DAILY BACKGROUND LEVELS

6.2.1. Basis for Calculation

Physiologically based pharmacokinetic (PBPK) models are convenient and useful methods for describing and predicting disposition of foreign chemicals in the body. These models take into account physiologic and biochemical processes such as blood flows, metabolism, and renal clearance, and describe the body according to its normal anatomy. PBPK models can, given adequate data, predict disposition from one exposure scenario to another and even from species to species. One such model was developed for 2,3,7,8-TCDF (King et al., 1983) and is used here with some modifications. The anatomic regions depicted in the King model are the blood, liver, fat, skin, and muscle. The remaining organs of the body are lumped together as the "carcass." Input may be by a variety of

routes, but for the purposes of this discussion is considered to occur through the gastrointestinal system by continuous chronic dosing. This is consistent with the findings of Chapters 4 and 5 that most of these compounds enter the body through the gastrointestinal tract as a result of the consumption of products containing animal fat. The pertinent equations follow.

For the liver:

$$V_L \frac{dC_L}{dt} = Q_L \left[C_B - \frac{C_L}{R_L} \right] - KL \frac{C_L}{R_L} + D \qquad (6\text{-}1)$$

Where,

V_L	=	Volume of the liver
C_B	=	Concentration of toxin in blood
C_L	=	Concentration of toxin in liver
t	=	Time
Q_L	=	Blood flow to liver
R_L	=	Equilibrium concentration ratio between liver and blood
KL	=	Clearance term (L/time)
D	=	Input or dosing function

The clearance in the liver is considered to be by metabolic processes.

For the fat:

$$V_F \frac{dC_F}{dt} = Q_F \left[C_B - \frac{C_F}{R_F} \right] \qquad (6\text{-}2)$$

Where all terms are analogous as those in Equation 6-1.

Note that there is no metabolic elimination assumed. The only disappearance of material from the fat is assumed to be diffusion driven and is accounted for in the above mass balance equation. Equations for the skin, carcass, and muscle are analogous to that for fat.

The equation for the blood is:

$$V_B\frac{dC_B}{dt} = Q_L\frac{C_L}{R_L} + Q_F\frac{C_F}{R_F} + Q_M\frac{C_M}{R_M} + Q_S\frac{C_S}{R_S} + Q_C\frac{C_C}{R_C} - Q_BC_B \qquad (6\text{-}3)$$

Where,

Q = Blood Flows
C = Concentrations
R = Equilibrium Concentration Ratios between tissue and blood
Subscripts:
B, L, F, M, S, C refer to blood, liver, fat, muscle, skin and carcass.

Some assumptions may be made to simplify the model for use to estimate daily background doses. If steady state is assumed, then the equations for the individual organs can be summed. The resultant equation for the liver is then:

$$D = \frac{(KL)C_L}{R_L} \qquad (6\text{-}4)$$

and at steady state

$$\frac{C_L}{R_L} = C_B \qquad (6\text{-}5)$$

and

$$C_B = \frac{C_{F,SS}}{R_F} \qquad (6\text{-}6)$$

and hence

$$D = \frac{(KL)C_{F,SS}}{R_F} \quad (6\text{-}7)$$

When clearance is expressed in days, D is the daily intake. Clearance can be approximated from the half-life information according to the following equations:

$$KL = k_e V_d \quad (6\text{-}8)$$

Where,

k_e = First order elimination rate constant
V_d = Volume of distribution

and

$$k_e = \frac{ln2}{t_{1/2}} \quad (6\text{-}9)$$

Where,

$t_{1/2}$ = Biological half-life of compound in body

The volume of distribution may be estimated as in King et al., (1983) according to:

$$V_{d,i} = V_i R_i \quad (6\text{-}10)$$

Where,

$V_{d,i}$ = Volume of distribution of organ, i
V_i = Actual volume of organ, i
R_i = Equilibrium concentration ratio between organ i and blood

With substitution equation (6-7) becomes:

$$D = \left[\frac{ln2}{t_{1/2}}\right] (V_i)\ (C_{i,ss}) \qquad (6\text{-}11)$$

Where,

V_i = Volume of the organ in which toxin is measured
$C_{i,ss}$ = Steady state concentration of toxin in organ

It is important to note that two major assumptions are in effect when the above formula is used to calculate average daily uptake. First steady state conditions are assumed. Given that the half-life of some of these compounds (e.g., 2,3,7,8-TCDD) are at least 5 years, it would take well over 15 years to reach 90 percent of steady state, and over 30 years to reach 99 percent of steady state levels. Thus, the assumption of steady state is only reasonable if background environmental concentrations are relatively similar and constant throughout the nation. Under such conditions even the normal movement from one geographical location to another would result in relatively constant exposures. Also implicit in this assumption is that bioavailability is relatively constant through the nation. Given that the source of this background exposure is believed primarily due to consumption of foods containing animal fat (see Chapters 4 and 5), the assumption of steady state for adults might be considered a reasonable assumption. Exceptions are those individuals who may for a portion of their adult lives be consuming foods with unusually high levels of these compounds. It would be expected, however, that those individuals would have higher than average body burdens, and hence would not be considered to have only average background exposure, but would rather be considered part of a source-specific exposure group. Conditions such as sudden weight loss and lactation would also alter the steady state condition. However, for purposes of calculating daily background exposure levels the sampling of tissues for body burden must be so designed to account for such deviations in the average. In summary, for adults (over 25 years of age) not in a source-specific exposure group, the steady state assumption is a reasonable approximation. It should be remembered, however, that the longer the biological half-life the longer it would take to reach steady state. A compound with a half

life of 10 years, for example, would take over 50 years to reach 90 percent of the steady state value.

The second major assumption is that these compounds are eliminated from the body by monophasic kinetics. Biphasic elimination is very possible for many of these compounds. Data gathered to calculate elimination rates or half-lives would only reveal biphasic elimination profiles if gathered several years after the last exposure. Using only the short term half-life would result in an underestimated value for half-life and an overestimate of daily intake. This is particularly problematic for those compounds with extremely long half-lives and for which few data exist. In Section 6.2.2., an approach to calculating half-lives for some of these compounds will be presented. Also, the elimination kinetics are assumed to be constant over the entire life of the individual. Sudden weight loss and lactation would, for example, be conditions which violate that assumption. Again, it would be assumed that for calculation of daily intake due to background exposure the body burden data from such individuals would be identified and calculations handled accordingly.

6.2.2. Daily Intakes

$$D = \left[\frac{ln2}{t_{1/2}}\right](V_i)(C_{i,ss})\left[\frac{1}{70KG}\right]$$

$$D = \left[\frac{ln2}{5.8years}\right]\left[14L \quad 1000\ \frac{ml}{L}\right]\left[6.72\frac{pg}{ml}\right]\left[\frac{1}{70KG}\right]\left[\frac{1year}{365days}\right]$$

$$D = 0.44 \quad pg/kg/day$$

Figure 6-1: Sample Calculation of Daily Intake for 2,3,7,8-TCDD

Figure 6-1 shows a sample calculation for 2,3,7,8-TCDD using the above procedure. A fat volume of 14 L was chosen, representing 20 percent of the body weight.

Also, for the purposes of this example, 1 ml of tissue was assumed to be equivalent to 1 gm.

Table 6-1 shows the estimated daily intake of 2,3,7,8-TCDD at several conditions. The range of daily intakes calculated are in agreement with those reported elsewhere (Fürst et al., 1991; U.S. EPA, 1994).

In order to perform similar calculations for other congeners three pieces of information are necessary. First, concentrations in the adipose tissues must be known. Second, the half-lives of the compounds within the body must be known. Third, some understanding of the kinetics and exposure conditions to assure that steady state conditions were achieved at the time of monitoring.

Concentrations of various congeners in adipose tissues can be found in several sources (Stanley et al., 1986; Schecter, 1991). Values range from around 2 ppt for 2,3,7,8-TCDF to several hundred ppt for 1,2,3,4,6,7,8,9-OCDD.

Half-lives could be determined from elimination data, if available. Methods have been suggested to determine the half-lives of such compounds from uptake data relative to 2,3,7,8-TCDD. Schlatter (1991) has proposed one such method. The following has been adapted from that proposed method. Manipulation of Equation 6-11 results in:

$$C_{TCDD} = \frac{D_{TCDD} \; t_{1/2,TCDD} \; V}{\ln 2} \qquad (6\text{-}12)$$

Where,

C_{TCDD}	=	Concentration of TCDD in body
D_{TCDD}	=	Daily Intake of TCDD
$t_{1/2,TCDD}$	=	Half-life of TCDD in body
V	=	Volume of body compartment

For some other congener x:

$$C_x = \frac{D_x \; t_{1/2,x} \; V}{ln2} \qquad (6\text{-}13)$$

Where symbols are same as for equation (6-12) and subscript x applies to compound x.

Table 6-1. Calculated Daily Intakes for 2,3,7,8-TCDD

Half-life (years)	Fat Volume (liters)	Fat Concentration (ppt)	Calculated Daily Intake (pg/kg/day)
5.8	14.0	6.72	0.44
7.0	14.0	6.72	0.37
5.8	14.0	5.00	0.33
7.0	14.0	5.00	0.27
5.8	7.0	6.72	0.22
7.0	7.0	6.72	0.18
5.8	7.0	5.00	0.16
7.0	7.0	5.00	0.14

Thus the ratio of concentrations of TCDD to x can be described by:

$$\frac{C_{TCDD}}{C_x} = \left[\frac{D_{TCDD}\ t_{1/2,TCDD}\ V}{ln2}\right]\ \left[\frac{ln2}{V\ D_x\ t_{1/2,x}}\right] \qquad (6\text{-}14)$$

With algebraic manipulation and simplification Equation 6-14 becomes:

$$t_{1/2,x} = \left[\frac{D_{TCDD}\ t_{1/2,TCDD}}{C_{TCDD}}\right]\ \left[\frac{C_x}{D_x}\right] \qquad (6\text{-}15)$$

Assuming intake, D, to be mostly from the food, especially animal fat products, D can be related to absorption from these foods according to:

$$D_{TCDD} = (k_{a,TCDD})\ (A_{TCDD}) \qquad (6\text{-}16)$$

Where,

$k_{a,TCDD}$ = Absorption rate constant for TCDD
A_{TCDD} = Concentration of TCDD in animal fat (diet)

and

$$D_x = (k_{a,x})\ (A_x) \qquad (6\text{-}17)$$

Where,

$k_{a,x}$ = Absorption rate constant for x
A_x = Concentration of x in animal fat (diet)

As a result the half-life for compound x can be described by:

$$t_{1/2,x} = t_{1/2,TCDD}\ \left[\frac{A_{TCDD}}{C_{TCDD}}\right]\ \left[\frac{C_x}{A_x}\right]\ \left[\frac{k_{a,TCDD}}{k_{a,x}}\right] \qquad (6\text{-}18)$$

When the absorption rate constants for each congener are equal or when the difference between them is small compared to differences in other parameters (concentration, half-lives), Equation 6-18 can be further simplified to:

$$t_{1/2,x} = t_{1/2,TCDD} \left[\frac{A_{TCDD}}{C_{TCDD}} \right] \left[\frac{C_x}{A_x} \right] \quad (6\text{-}19)$$

Before using the above approach to calculate half-lives for some of the other substances of interest it is well to briefly highlight one of the assumptions in this approach. The relationship of half-life to elimination as described in Equation 6-9 only applies to simple single compartment kinetics. These compounds would not necessarily be expected to behave in such a manner. However, the error introduced by such an assumption is not great if the one phase predominates over the other, or if it is remembered that the calculation applies to one phase only. In fact, as will be discussed in a subsequent section, it is believed that for these chemicals the relationship between half-life and elimination as described here is a reasonable approximation.

It should be noted that for some of these substances exposure is expected from other than food sources. For such cases Equation 6-18 would be modified to include these other sources as follows:

$$t_{1/2,x} = t_{1/2,TCDD} \left[\sum \frac{k_{a,i,TCDD} \; A_{i},TCDD}{C_{TCDD}} \right] \left[\sum \frac{C_x}{k_{a,i,x}} \; A_{i,x} \right] \quad (6\text{-}20)$$

Where,

$k_{a,i,TCDD}$ = Absorption rate constants for TCDD from each of the i media
$A_{i,TCDD}$ = Concentration of TCDD in each of the i media
$k_{a,i,x}$ = Absorption rate constants for x from each of the i media
$A_{i,x}$ = Concentration of x in each of the i media
Other symbols: As previously defined

Again, if the differences between the absorption rate constants for TCDD and x are judged to be small, then the variation of Equation 6-19 can be used, presented as Equation 6-21, Table 6-2 shows the results of some half-lives calculated in this manner.

$$t_{1/2,x} = t_{1/2,TCDD} \left[\sum \left(\left(\frac{A_{i,TCDD}}{C_{TCDD}} \right) \left(\frac{C_x}{A_{i,x}} \right) \right) \right] \quad (6\text{-}21)$$

The half-lives calculated using Equation 6-19 for the first three compounds in Table 6-2 agree with those calculated by Schlatter (1991). The large difference in the two calculations for OCDD is due to significant differences in absorption rates between the TCDD and the OCDD. Schlatter (1991) notes that for some compounds, including OCDD, corrections were made of differences in absorption. No explanation was offered on how this was done. In U.S. EPA (1993), results are summarized that indicate a possible several-fold greater oral
absorption of TCDD over OCDD. This adjustment would result in a calculated half-life closer to that calculated by Schlatter.

In summary, this section illustrates a method for calculating the half-lives of similar behaving compounds. Several pieces of information are necessary: 1) the concentration in the body of 2,3,7,8-TCDD; 2) the half-life of 2,3,7,8-TCDD; 3) the concentration of the substance of interest in the body; 4) the concentration of the substance of interest in the media from which exposure occurs; and 5) the differential absorption rates for TCDD and the substance of interest.

From the half-life information, average daily intakes may be calculated, when steady state can be assumed, by using Equation 6-12. Caution should be exercised when

Table 6-2. Half-life Calculations

Congener	Concentration in Food[a] (ppt)	Concentration in Body[b] (ppt)	Half-life[c] (years)	Half-life[d] (years)
2378-TCDD	0.23	6.72	7.0	6.0
2378-TCDF	0.84	3.9	1.11	1.3
12378-PeCDD	0.7	21.5	7.35	5.0
23478-PeCDF	1.4	36.8	7.94	6.3
OCDD	19.2	653.0	8.14	50.0

[a] Concentrations in food were selected as examples of levels in animal-derived products from Schlatter (1991).

[b] Concentrations in body (adipose tissue) were all taken from Schecter (1991).

[c] Calculated using Equation 6-19, except for TCDD.

[d] Calculated by Schlatter (1991), except for TCDD.

calculating daily intakes for those compounds with very long half-lives such as OCDD in the above example.

6.3. COMPARTMENTAL MODELING

As previously discussed and also discussed elsewhere (U.S. EPA, 1994), PBPK models are very useful for describing and predicting the disposition of chemicals in the body. They are generally designed for predicting some measure of dose at a target site. They are also used to extrapolate from one species to another, between different doses, and between different routes of exposure. Several PBPK models have been published specifically for 2,3,7,8-TCDD (Leung et al., 1990; Leung et al., 1988). Also, as previously discussed, a model for 2,3,7,8-TCDF (King et al., 1983) is also available and from which were derived the equations for estimating daily intake from body concentrations at steady state conditions. Most of these models have been developed to describe in great detail the metabolism and binding of TCDD within the body, for the purpose of estimating target tissue dose.

6.3.1. Pharmacokinetic Model

Assuming a linear relationship between the concentrations in the fat and the body at low exposure concentrations and the near linear elimination profile, a simpler model relating exposure, whole body elimination, and whole body concentration is developed here. As described earlier, after a prolonged exposure most of the body's organs can be assumed to have very similar kinetic profiles and can thus be lumped together. The fat, while sharing such a similar profile, is kept separate because of its important role in storing most of the body burden and because it has been the most typically monitored tissue. The three compartments in this model are blood, fat, and a "body" representing all other tissues. The model is a flow- or perfusion-limited model with the assumption that the toxin is well stirred or uniformly distributed within each compartment. The pertinent equations for the model follow. The rate of change of concentration of toxin in the body is estimated by:

$$\frac{dC_{bo}}{dt} = \frac{Q_{bo}\left[C_B - \frac{C_{bo}}{R_{bo}}\right] - K(C_{bo}) + D}{V_{bo}} \qquad (6\text{-}22)$$

Where:

dC_{bo}/dt	=	Rate of change of concentration of toxin in body (bo)
Q_{bo}	=	Blood flow (volume/time) to body
C_B	=	Concentration of toxin in blood (B)
R_{bo}	=	Equilibrium concentration ratio of toxin between body and blood
K	=	Clearance (volume/time) of toxin from body
V_{bo}	=	Volume of body
D	=	Intake of toxin

The rate of change of concentration of toxin in the fat is estimated by Equation 6-23 below:

$$\frac{dC_F}{dt} = \frac{Q_F\left[C_B - \frac{C_F}{R_F}\right]}{V_F} \qquad (6\text{-}23)$$

Where,

dC_F/dt	=	Rate of change of concentration of toxin in fat (F)
Q_F	=	Blood flow (volume/time) to fat
R_F	=	Equilibrium concentration ratio of toxin between fat and blood
V_F	=	Volume of fat

The integral of the above differential equation (Eq. 6-23) over time gives the actual concentration.

The rate of change of concentration of toxin in blood is estimated by Equation 6-24 below:

$$\frac{dC_B}{dt} = \frac{Q_F \left[\frac{C_F}{R_F}\right] + Q_{BO} \left[\frac{C_{bo}}{R_{bo}}\right] - C_B(Q_F + Q_{bo})}{V_B} \qquad (6\text{-}24)$$

Where,

dC_b/dt = Rate of change of concentration of toxin in blood (B)

It should be noted that the description of intake is somewhat different than what is typically found in most PBPK models. D here is actually a dose rate. That is, D is in terms of pg/kg/day coming into the body as a dose, not just a concentration in the food, drinking water, or air. The usual description for gastrointestinal absorption of toxin from food would be

$$D = k_a F_c \qquad (6\text{-}25)$$

Where,

k_a = Absorption rate constant
F_c = Concentration of toxin in food

In this case, because of inadequate knowledge regarding the absorption rate constants for many of the congeners, a dose rate is used instead. This does not allow for estimation of body burden directly from environmental concentrations (e.g., F_c in Equation 6-25). As more data are collected, more accurate values of the parameters and descriptions of absorption functions can be input into Equation 6-22. For the present, other approaches

can be used to relate concentration in the environmental media to daily intake (see Section 6.4.1).

6.3.2. Model Utilization

Most of the model's parameters are known or can be estimated from experimental data for many of these toxins. For example, the equilibrium concentration ratios between the fat and the body and between the fat and the blood for 2,3,7,8-TCDD are approximately 10 and 100, respectively, on a tissue basis. The blood flows and compartment volumes are well known. One parameter that had to be estimated when applying this model to 2,3,7,8-TCDD was the clearance term K. This was done by first allowing the model to simulate elimination as though exposure was suddenly terminated (D becomes zero). Initial concentrations for the tissues were taken as those typically expected in the general population (7.0 ppt in the fat). The value of K was then adjusted until the model predicted a half-life of 7 years. Values of clearance for the other compounds in this series would be determined similarly. The necessary information includes the equilibrium concentration distribution ratios, the half-lives of the compounds, and some reasonable approximation of steady state fat concentrations.

With an estimated value for the clearance, the model can now be used with various exposure inputs to establish body burdens of toxin. The model can also be used to estimate elimination profiles from the body. In addition, events such as lactation can be incorporated into the model with knowledge about the appropriate parameters.

Figure 6-2 shows the results of the model run describing the elimination of 2,3,7,8-TCDD from fat. The clearance rate was adjusted to predict a half-life of 7 years. The same clearance value was used with different starting conditions (concentration of TCDD in tissues) and the model produced a half-life of 7 years. Next, the model was used with a constant daily intake as an input. Figure 6-3 shows the resulting profile of 2,3,7,8-TCDD in the fat. Figure 6-3 shows the results of a model run using an input of 0.44 pg/kg/day. Note that the steady state fat concentrations are approximately 7.0 ppt. The clearance rate used in this model run had been independently determined in the previous run based on reported half-life values. Thus, for these conditions this model does an adequate job of

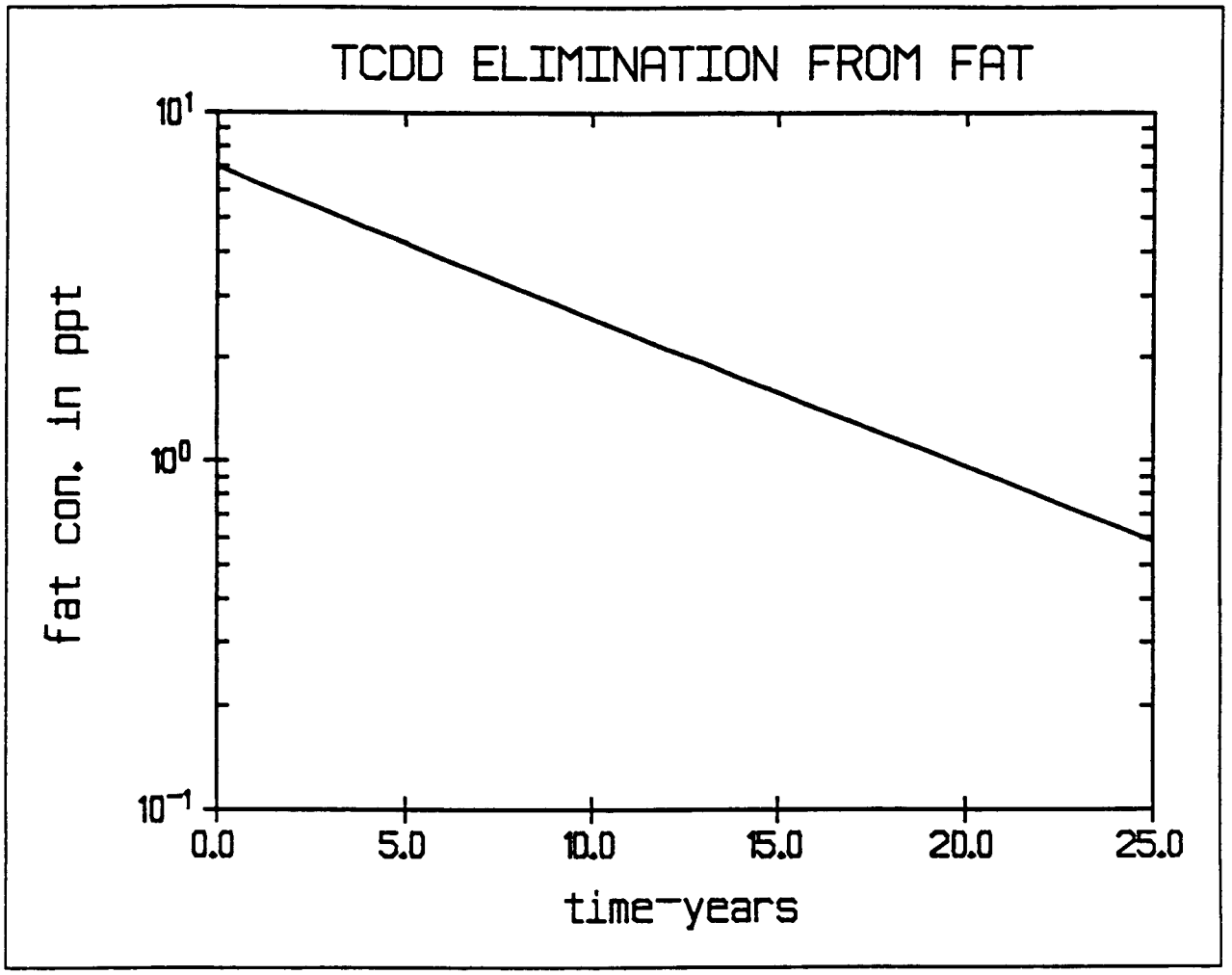

Figure 6-2. Model Estimates of Elimination of 2,3,7,8-TCDD from Fat

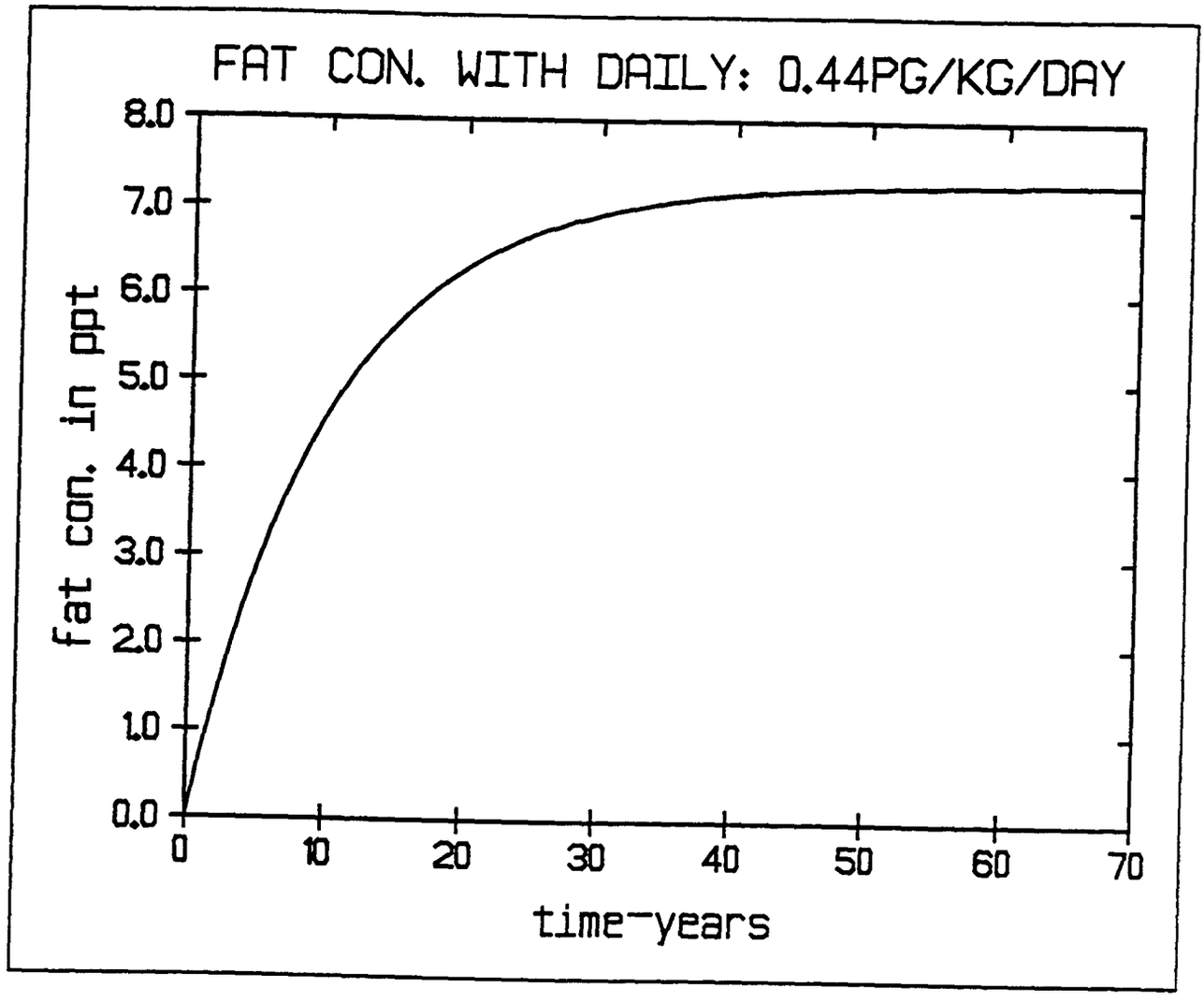

Figure 6-3. Accumulation of TCDD in Fat with 0.44 pg/kg/day dose - Human

predicting tissue levels of 2,3,7,8-TCDD. Figure 6-4 shows a similar profile for a 0.30 pg/kg/day dose. The daily intakes chosen were similar to those calculated by the steady state equations in Section 6.1.2 (Table 6-1). Note that the steady state fat levels predicted by the pharmacokinetic model agree closely with those used as a starting point for the steady state calculation using seven years for the half-life. This three compartment model appears to provide reasonable approximations of body burden, at least under the circumstances that have been tested. The necessary information for use with other substances in this series include the equilibrium distribution ratios between fat and blood and between fat and the rest of the body. An estimate of the half-life is also needed in order to establish an appropriate value for the clearance term used in the model. Table 6-3 shows the results when the model was adjusted for other substances. The congener-specific TEQ intakes can be added together to arrive at a TEQ-based total daily intake for all the congeners of interest to a particular assessment.

Under certain circumstances, it might also be possible to use the compartmental model on a total TEQ basis. Considering, for example, a mixture of dioxins and furans whose collective biophysical properties are similar to those of 2,3,7,8-TCDD the model could be applied to approximate daily intake from steady-state fat levels. For example, Schecter (1991) reports the blood lipid levels in a sample of 85 persons from Germany to be 42 ppt TEQ (CDDs and CDFs). Using that figure and the parameters of 2,3,7,8-TCDD, the model calculates a daily intake of 2.64 pg TEQ/d/kg. Fürst et. al (1991), based on food consumption patterns of the German population, estimated a daily intake of 2.3 pg TEQ/d/kg. Obviously great caution should be taken before using such an approach. Such estimates should only be relied upon if there is strong evidence that the mix of congeners is such that the collective properties of the mixture result in properties similar to those of 2,3,7,8-TCDD.

6.3.3. Determining Liver Concentrations from Fat Levels

As mentioned previously, higher resolution PBPK models are necessary to estimate and predict concentration at cellular and sub-cellular targets (*vidae supra*). At the present time, many of the data necessary to develop and apply these models to estimate target

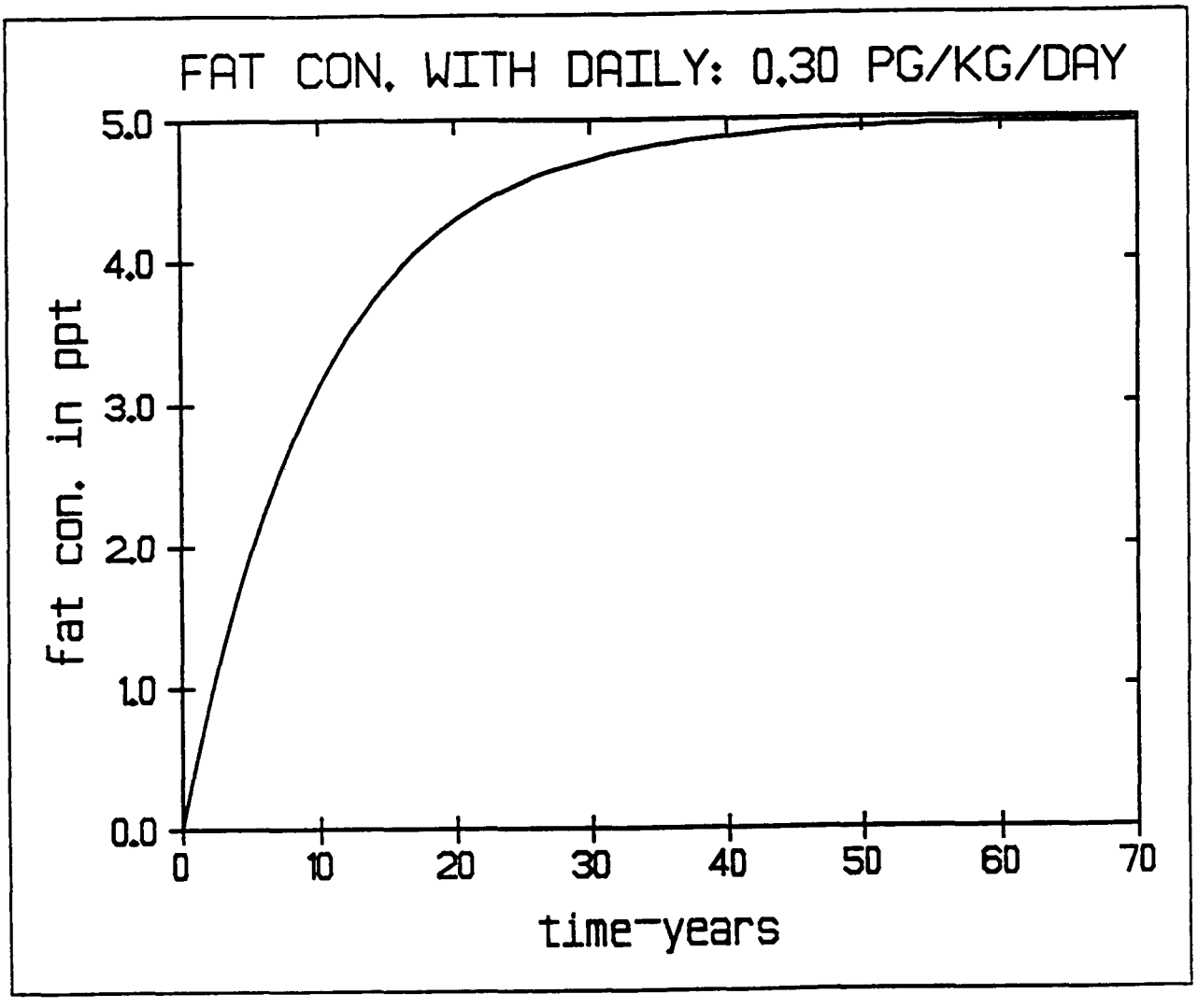

Figure 6-4. Accumulation of TCDD in Fat with 0.30 pg/kg/day dose - Human

Table 6-3. Model-Determined Daily Intakes

Congener	Half-life (yrs)[a]	Fat Concentration (ppt)[b]	Intake (pg/kg/day)	Intake-TEQ (pg/kg/day)
OCDD	50[c]	1174.0	23.48	0.02
1,2,3,7,8-PeCDF	8	2.8	0.55	0.03
2,3,4,7,8-PeCDF	8	13.0	0.93	0.47

[a] Taken from Table 6-2.
[b] Taken from Schecter (1991).
[c] Value determined by Schlatter (1991).

tissue or cellular dose in humans are lacking. Andersen and Greenlee (1991) provide an approach that uses the equations of a PBPK model (Leung et al., 1990) to predict liver concentrations from monitored fat concentrations. It should also be noted that blood or milk concentrations expressed on a per lipid basis could also be used. Basically the approach calculates the ratio of fat to liver concentration by dividing the tissue concentration equations of the PBPK model as follows:

$$\frac{C_L}{C_F} = \left[\frac{P_L}{P_F} + \frac{1}{V_L\ P_F}\left[\frac{BM_1}{KB_1 + CVL} + \frac{BM_2(T)}{KB_2 + CVL}\right]\right]\frac{CVL}{CVF} \qquad (6\text{-}26)$$

Where,

C_L, C_F	=	Concentrations of toxin in liver and fat
C_{VL}, C_{VF}	=	Concentrations of toxin in venous blood from liver and fat
P_L, P_F	=	Liver:blood and Fat:blood partition coefficients of toxin
V_L	=	Volume of Liver compartment
BM_1, KB_1	=	Forward and reverse binding constants for binding of toxin with Ah receptor
$BM_2(T)$	=	Forward binding constant with microsomal binding protein - time dependent upon the amount of inducible microsomal binding protein
KB_2	=	Reverse binding constant for microsomal binding protein

Andersen and Greenlee (1991) further simplify Equation 6-26 for various limiting conditions. For the case of very low doses where $CVL << KB_1$, KB_2 and their is no induction of the cytochrome P450 enzyme (microsomal binding protein), the equation simplifies to:

$$\frac{C_L}{C_F} = \frac{P_L}{P_F} + \frac{1}{P_F\ V_L}\left[\frac{BM_1}{KB_1} + \frac{BM_{2(0)}}{KB_2}\right] \qquad (6\text{-}27)$$

Where,

$BM_{2(0)}$	=	Basal level (non-induced) binding level of P450 (microsomal binding protein)

For the case where $KB_2 << CVL << KB_1$, P450 is maximally induced but binding is less than half saturation, Equation 6-26 becomes:

$$\frac{C_L}{C_F} = \frac{P_L}{P_F} + \frac{1}{P_F V_L}\left[\frac{BM_{2(\max)}}{KB_2}\right] \quad (6\text{-}28)$$

Where,

$BM_{2(max)}$ = Maximally induced binding level of P450

For the case where $CVL >> KB_1, KB_2$, Equation 6-26 becomes:

$$\frac{C_L}{C_F} = \frac{P_L}{P_F} \quad (6\text{-}29)$$

Andersen and Greenlee (1991) provide values for each of the above conditions for experimental animals. It can be readily observed from examining Equation 6-26 that when binding levels are very small the ratio of concentration between liver and fat is influenced mostly by the ratio of partitioning coefficients.

With this approach and by knowing the necessary parameters Equation 6-26 can be used to estimate liver concentrations from fat (including blood lipid and milk lipid) concentrations. Andersen and Greenlee (1991) further suggest that most of the necessary binding parameters can be determined from in-vitro studies. Further, the pharmacokinetic model from which Equation 6-26 was derived can be used to estimate and predict cellular concentrations (both free and bound) under various exposure conditions. The equations used by Leung et al. (1990) or other like equations provide estimates of amount bound to intracellular receptors sites, and can thus provide a relationship between multiple binding sites. Denison et al. (1991) suggest that binding to the Ah receptor is only one of several steps necessary for 2,3,7,8-TCDD to have an intracellular toxic effect. As further knowledge becomes available about the mechanism and kinetics of each step, the model

can be expanded to include these other processes such as DNA enhancing and hormonal modulation. The pharmacokinetic model will therefore become a pharmacodynamic model which will more explicitly link exposure to effect. Also, other tissues can be more specifically described in the model, if the mechanism of action data so warrant.

6.4. INTAKES THROUGH DAILY EXPOSURE

6.4.1. Determination of Daily Intake Dose from Exposure Concentrations

As was discussed in Section 6.3.1, it would be most advantageous to know more about the kinetics of absorption in the various animal species and the human. This is necessary for both extrapolation between species in the risk assessment and for determining body burdens from levels in the exposure media. For the time being, until more data become available regarding the kinetic absorption constants, a slightly modified approach can be used. Basically, the needed information is the concentration of the toxins in the media, the fraction of toxin absorbed from each of the media, and the amount of media coming into contact with the body. The following equation describes this in more detail.

$$D = \sum f_i \, C_i \, U_i \qquad (6\text{-}30)$$

Where,

D	=	Daily Intake
f_i	=	Fraction absorbed from various i media
C_i	=	Concentration in various i media
U_i	=	Amount of contact of i media, (gm/time for food, L/time for air, etc.)

This approach should be used with caution. The major assumption which impacts upon Equation 6-30 is that the fraction absorbed is constant across various concentrations and doses. As discussed in Section 6.4.2 and in U.S. EPA (1994), this assumption cannot always be considered to be sound. It most probably only applies at low doses and within

any one species. It is an approach which, with care, can be used for certain conditions to give estimates until more reliable kinetic absorption data become available.

6.4.2. Dose Through Lactation

There is great concern regarding the potential dose resulting from lactation. Given the body burdens discussed in previous chapters and sections, lipid soluble substances might be expected to compartmentalize into milk and thus be transferred to nursing infants. Methods are needed to assess this potentially important route of exposure into the body.

6.4.2.1. *Concentration in the Milk*

The first step to calculating the daily intake for infants is to determine the levels in mother's milk. There are two general methods that can be used as a basis. The first assumes that levels in maternal fat remain at steady-state and reach an equilibrium with milk fat. Under these assumptions, Equation 5-1 (repeated here as Equation 6-31) can be used to calculate the levels in maternal milk:

$$C_{milk\ fat} = \frac{mhf_1}{0.693 f_2} \qquad (6\text{-}31)$$

where,

$C_{milk\ fat}$ = Concentration in maternal milk (pg/kg of milk fat)
m = Average maternal intake of dioxin (pg/kg body weight/day)
h = Half-life of dioxin in adults (days)
f_1 = Proportion of ingested dioxin that is stored in fat
f_2 = Proportion of mother's weight that is fat

Application of this equation to 2,3,7,8-TCDD, where an intake of 0.5 pg/kg/day, a half-life of 2555 days (7 years), 0.9 for f_1 and 0.3 for f_2 are assumed, results in a concentration in maternal milk fat of 5.6 ppt. This is higher than the 3.3 ppt. reported by Schecter et al., (1989).

A second and theoretically more accurate approach uses some type of physiologically based pharmacokinetic model to estimate the dynamically changing concentrations in mother's milk. One way to accomplish this is to add a mammary compartment to the compartmental model described in Section 6.3. The model is then extended to depict the toxin's transport into the milk. In the simplest form the following two equations would be added:

$$\frac{dC_{ma}}{dt} = \frac{Q_{ma}(C_B - \frac{C_{ma}}{R_{ma}}) - F_{mi}(\frac{C_{ma}}{R_{mi}})}{V_{ma}} \quad (6\text{-}32)$$

where,

dC_{ma}/dt = Change in the concentration of dioxin in mammary compartment
Q_{ma} = Blood flow to mammary compartment
C_b = Concentration of dioxin in blood
R_{ma} = Mammary tissue to blood partition coefficient for dioxin
F_{mi} = Flow of milk
R_{mi} = Milk to mammary tissue partition coefficient for dioxin
V_{ma} = Volume of mammary compartment

and

$$\frac{dC_{mi}}{dt} = \frac{F_{mi}(\frac{C_{ma}}{R_{mi}})}{V_{mi}} \quad (6\text{-}33)$$

where,

dC_{mi}/dt = Change in concentration of dioxin in mother's milk

V_{mi} = Volume of milk

Other symbols as previously defined.

When the model is actually implemented, the changes in proportion of body fat in the mother that normally occur during lactation are taken into account. Observation of the two previous equations quickly shows that several new parameters are now added to the compartmental model. Many of these parameters have not been determined for most of the congeners of interest. In fact, even some of the physiologic and anatomic parameters are not readily available. Thus, for the time being it may be best to use some type of steady-state model and Equation 6-31 or to actually use monitored data for calculating dose to a lactating infant. It should be noted that the model was applied for 2,3,7,8-TCDD and parameters were adjusted to predict levels near the 3.3 ppt value published by Schecter et al. (1989). This is not a validation of the model or its parameters; of interest, however, is that the model predicted the same ratio between milk lipids and plasma lipids as reported by Schecter et al. (1989).

6.4.2.2. *Dose to Infant*

There are a number of measures of dose that can be used to compare the impact of exposure through lactation versus exposure through background. A common measure of dose, described in Chapter 5, is to calculate an average daily dose (ADD). Equation 5-2 (repeated here as Equation 6-34) describes such a calculation for the infant:

$$ADD_{infant} = \frac{C_{milk\ fat}\ f_3\ f_4\ IR_{milk}\ ED}{Bw_{infant}\ AT} \qquad (6\text{-}34)$$

where,

ADD_{infant} = Average daily dose to the infant (pg/kg/d)

IR_{milk} = Ingestion rate of breast milk (kg/d)

ED = Exposure duration (year)

BW_{infant} = Body weight of infant (kg)
AT = Averaging time (year)
f_3 = Fraction of fat in breast milk
f_4 = Fraction ingested contaminant which is absorbed

Assuming a concentration of 2,3,7,8-TCDD in milk fat of 3.3 ppt, values for f_3 and f_4 of 0.04 and 0.9, respectively, an average infant body weight of 10 kg, an exposure duration of one year, an ingestion rate of milk of 800 g/d, and an averaging time of one year, an ADD equal to 9.5 pg/kg/d is calculated. Using the same assumptions, except for an averaging time of 70 years (the entire assumed lifetime), an ADD equal to 0.135 pg/kg/d is calculated. Thus, depending upon the averaging time, lactation results in ADD similar to that resulting from background (0.135 pg/kg/d compared to 0.51 pg/kg/d) or an ADD over an order of magnitude higher (9.5 pg/kg/d compared to 0.51 pg/kg/d). Little agreement exists regarding the appropriate choice of an averaging time for less than lifetime exposures. This is especially true for cases where exposure is occurring in a particularly sensitive developmental period. Lifetime averaging may be used for long time or even lifetime exposures, but the logic of applying it to short exposures is not clear.

Equally unclear is the utility of the ADD calculation itself. The ADD is actually an average intake over an arbitrarily chosen period of time. The significance of the ADD is not apparent, especially in cases of compounds, such as the CDDs and CDFs, that reach steady-state levels during chronic exposure.

It is recommended that other measures of dose be examined. As advanced and new mechanistic knowledge develops, new measures of dose should be used and examined. Recent studies (Andersen and Greenlee, 1991; Andersen et al., 1993) show the importance of receptor-mediated processes. The actual toxicologically relevant dose may be related to the induced production of specific hepatic proteins. Scientific research is still needed to determine the exact role these play in the various toxic responses that may be caused by the CDDs and CDFs. As this type of mechanistic information develops, and its relevance to humans becomes better established, pharmacokinetic models will be

expanded to become pharmacodynamic models and then more realistic measures of dose can be determined.

For the time being, macroscopic measures other than the ADD should also be examined for assessment purposes. One approach to estimating such measures is to use the compartmental model described in Section 6.3. For the case of infants and children, the model is modified to account for the changing body weight of the child during the first 20 years of life. The model is used here under each of the three following exposure conditions for 2,3,7,8-TCDD:

- One year lactational exposure at levels corresponding to a milk fat concentration of 3.3 ppt followed by 69 years exposure at levels corresponding to background daily intakes of 0.51 pg/kg/d.
- 70 year exposure at levels corresponding to background daily intakes of 0.51 pg/kg/d.
- One year lactation exposure at milk fat concentration of 3.3 ppt.

Results of the simulation reveals several things. Figures 6-5 through 6-7 show the fat concentration profiles after the above three exposure scenarios for 2,3,7,8-TCDD. Figure 6-5 shows the fat level to peak quickly during the lactation period and then diminish until it reaches the steady-state level of about 8.0 ppt (8000 pg/kg). This is contrasted to Figure 6-6 where only background (no lactation exposure) is simulated. Note that in both cases the steady-state fat levels are 8.0 ppt. Lactation causes a temporary peak that diminishes over the next several years. Figure 6-7 shows the results of the simulation for the lactational phase only. This scenario assumed no further exposure after lactation ceased and was performed to investigate the impact of the lactational exposure apart from background exposure. Note that the half-life during the childhood years is shorter than that for adults (discussed in previous sections). This shorter half-life may be attributed to the changing size of the body and the compartments represented in the model. In fact, after age 20 (after which the body weight is assumed to remain constant) the model predicts the same half-life as previously discussed ($7 \leq t_{1/2} \geq 8$ years). Careful inspection

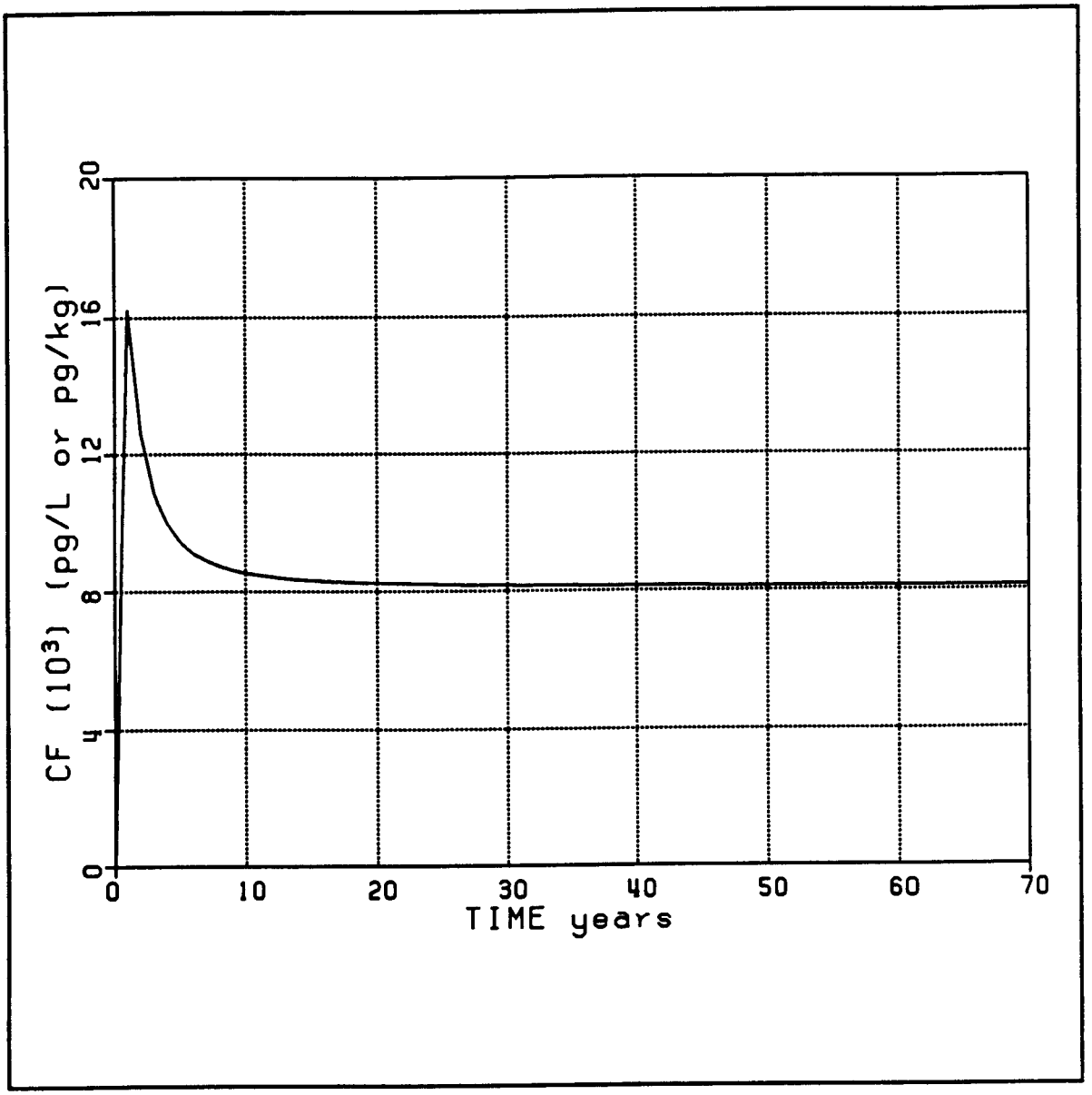

Figure 6-5. Combined Exposure Adipose Tissue Concentration

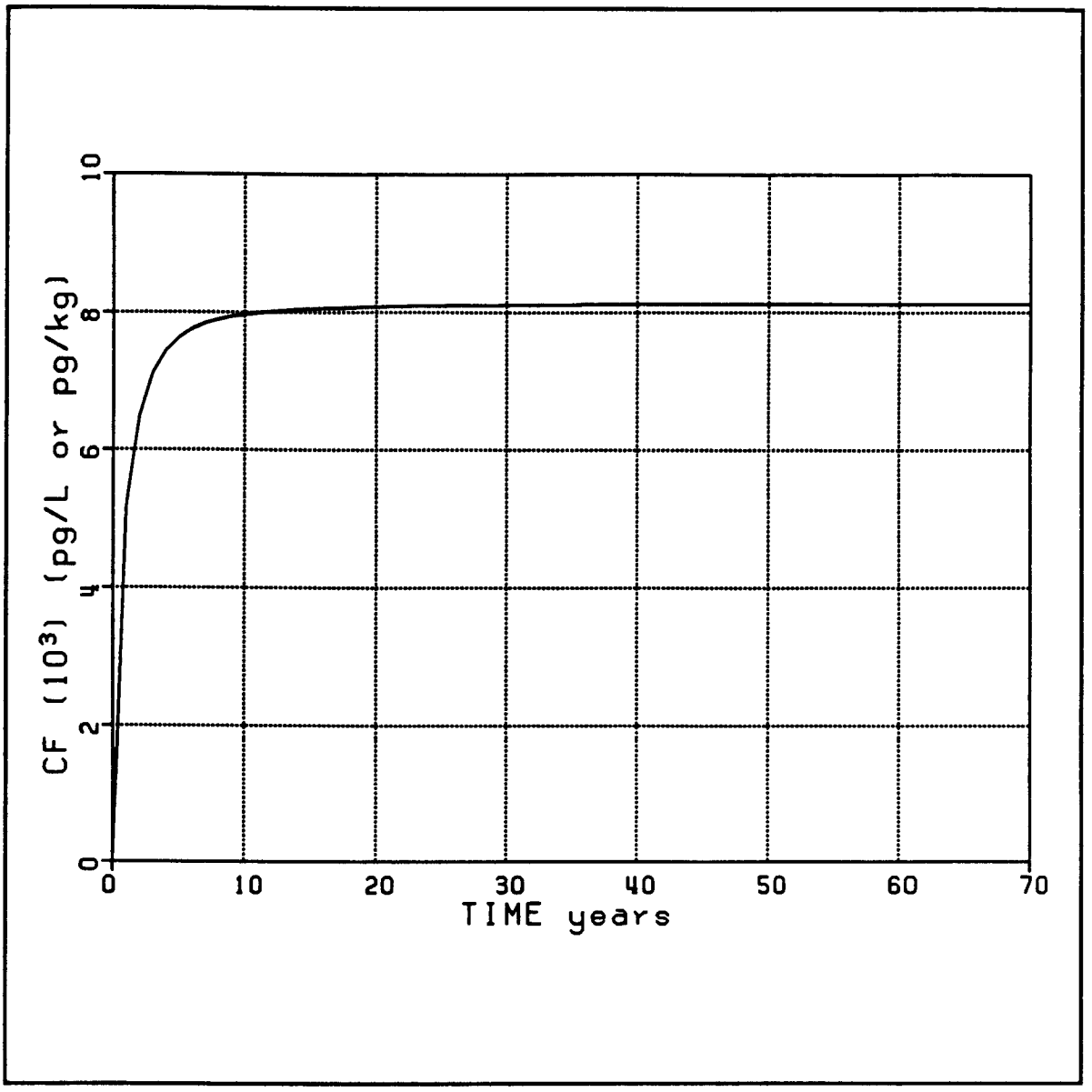

Figure 6-6. Background Exposure Adipose Tissue Concentration

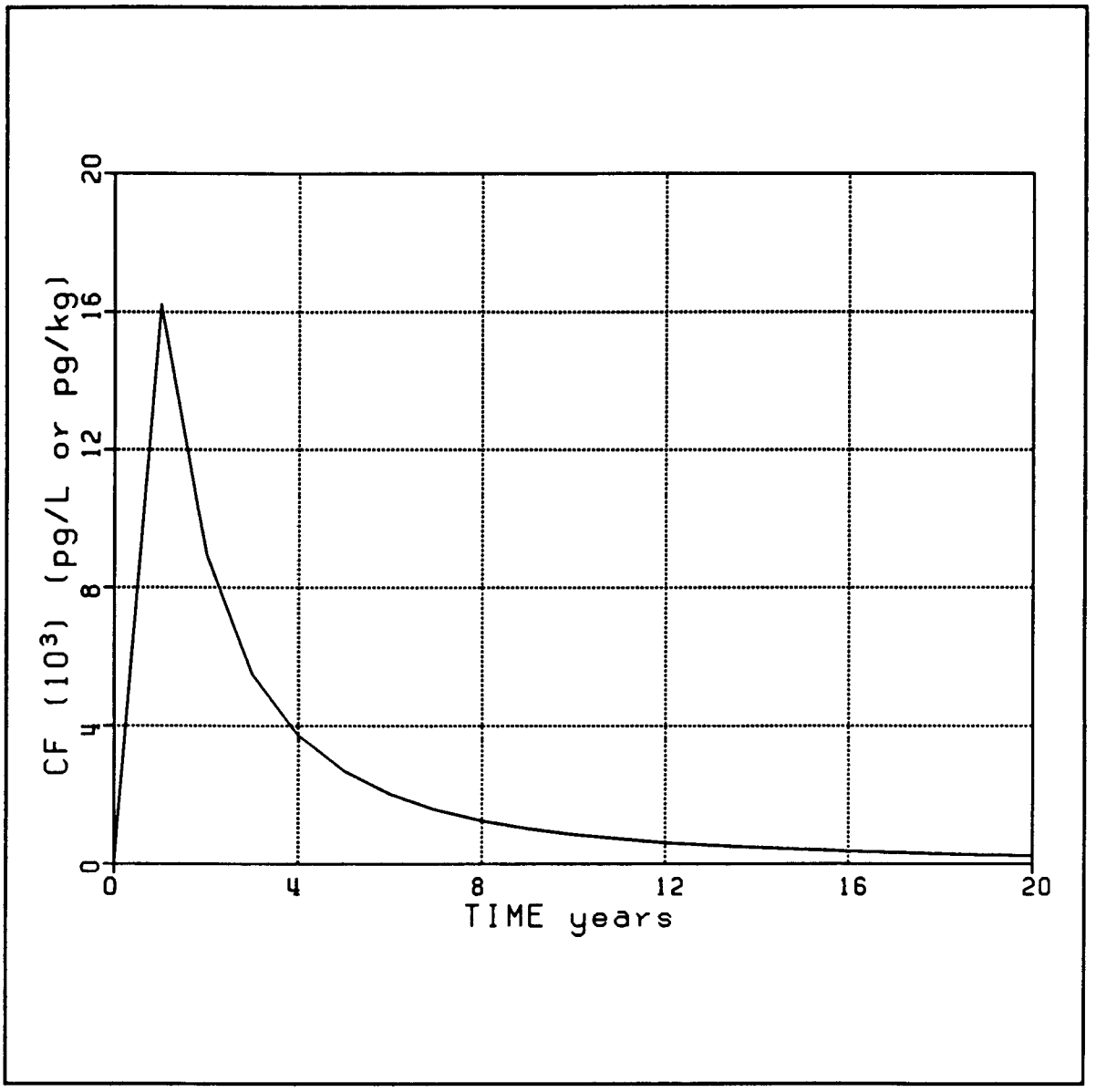

Figure 6-7. Concentration After Lactational Exposure Only

of Figures 6-5 and 6-6 also reveals that the time to reach steady-state is the same as discussed in previous sections (> 30 years).

Other measures of dose can also be used for comparison purposes. Care should be taken when ascribing meaning to different measures of dose, especially when exposure patterns of widely different duration are compared. Additional complexity is added by the fact that the lactational exposure occurs during the early developmental period of the individual. Given, these caveats, it may still be worthwhile to look at time integral (area under the curve or AUCs) measures of mass that has resided in the body throughout the exposure period. This is not a simple calculation of intake, but rather a measure of cumulative mass within the body as calculated by the model. The time integral of the mass in the body compartment (AUCBO) is used here for discussion and comparison. Lactation exposure during the first year and background exposure during the remaining 69 years results in an AUCBO at 70 years of 3.01×10^6 pg-years. Seventy years of background exposure with no lactational exposure results in 2.95×10^6 pg-years. The one year lactation exposure results in 7,862 pg-year at the one year mark. Obviously, in terms of pg-years the contribution from lactation is minor compared to background exposure.

It is not clear, however, whether this is an appropriate measure of dose to compare exposure patterns occurring at very different times of the lifetime. This same measure of dose can be averaged over the exposure time and then compared. The results appear different when the above three AUCBOs are converted to a pg/kg/day basis. The AUCBO averaged over exposure for the combined lactation and background exposure is 1.68 pg/kg/day ([3.01×10^6 pg-years]/70 kg/[365 d X 70 years]), 1.64 pg/kg/day for the background only case, and 2.15 pg/kg/day ([7,862 pg-years]/10 kg/365 d X 1 year]) for the lactational portion of exposure. Using this time-averaged measure, it appears that the one year lactational phase contributes slightly more, on a daily average basis, than the 69 year background phase. In addition, for some toxic end-points the first year of life may be more vulnerable than later years. How any of these measures are related to risk remains unknown and caution should be exercised before drawing conclusions. The goal here is to present different methods that might be used for comparison purposes. As mentioned

previously, as the mechanisms of action become better elucidated other more appropriate measures of dose should be used to make relative risk comparisons.

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APPENDIX A. ENVIRONMENTAL CHEMISTRY

The tables in this appendix are discussed in Chapter 2. References listed at the end of each table are included in the reference list at the end of Chapter 2. Following are the tables included in this Appendix:

Page

Table A-1. Physical and Chemical Properties For the Dioxin, Furan, and PCB Congeners A-2

Table A-2. Rankings For the Physical and Chemical Property Literature A-17

Table A-1. P-Chem Properties for the Dioxin, Furan, and PCB Congeners

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Tetrachlorodibenzo-p-dioxins (MW = 321.98)														
1,2,3,4-TCDD 30746-58-8	4.70E-07- 6.30E-04	25	5,38,46	1.81E-08- 4.80E-08	25	9,33	(3.7E-05)	5	(5.9)- (8.8)	5,7,8,10 ,26,29				
1,2,3,6-TCDD 71669-25-5									6.86	10				
1,2,3,7-TCDD 67028-18-6	4.30E-04	20	6	(7.5E-09)	25	9	(7.4E-06)	19	6.48- (8.5)	7,8,10, 26	5.97	45	5.42E-04[c]	24
1,2,3,8-TCDD 53555-02-5									6.48	10				
1,2,3,9-TCDD 71669-26-6									6.39	10				
1,2,4,6-TCDD 71669-27-7									6.10	10				
1,2,4,7-TCDD 71669-28-8									6.25	10				
1,2,4,8-TCDD 71669-29-9									6.25	10				
1,2,4,9-TCDD 71665-99-1									6.10	10				
1,2,6,7-TCDD 40581-90-6														
1,2,6,8-TCDD 67323-56-2									6.43	10				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[b]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,6,9-TCDD 40581-91-7														
1,2,7,8-TCDD 34816-53-0									6.38	10				
1,2,7,9-TCDD 71669-23-3									6.86	10				
1,2,8,9-TCDD 62470-54-6														
1,3,6,8-TCDD 33423-92-6	3.20E-04- (6.0E-04)	20-25	6,7,38	(5.2E-09)- 4.03E-06	20-25	7,9	6.81E-05	7	6.29- (9.0)	7,8,10, 26			2.17E-03[c]	24
1,3,6,9-TCDD 71669-24-4									6.25	10				
1,3,7,8-TCDD 50585-46-1				(6.3E-09)	25	9			6.30	10				
1,3,7,9-TCDD 62470-53-5									6.39- 7.06	8,10				
1,4,6,9-TCDD 40581-93-9									6.38	10				
1,4,7,8-TCDD 40581-94-0									6.39	10				
2,3,7,8-TCDD 1746-01-6	7.91E-06- 4.83E-04	17-22	1,2,27, 36,50	7.40E-10- 3.38E-08	25	2,3,9, 34	(1.6E-05)	2,3	6.42- (7.0)	2,4,8,10 50	5.68- 7.42	32,47 48,49 50	2.2E-03[b]- 3.3E-02[d]	22,30
Congener Group Average	(3.5E-04)	25	20	(8.1E-07)	25	20	(3.2E-05)	20	(6.4)	20	(6.2)	20		

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Pentachlorodibenzo-p-dioxins (MW=356.42)														
1,2,3,4,6-PeCDD 67028-19-7									6.30	10				
1,2,3,4,7-PeCDD 39227-61-7	1.20E-04- (1.7E-04)	20-25	6,38	(6.6E-10)	25	9	(2.6E-06)	19	6.60- (9.7)	7,8,10, 26	5.68	45	9.8E-05[c]	23
1,2,3,6,7-PeCDD 71925-15-0									6.74	10				
1,2,3,6,8-PeCDD 71925-16-1									6.53	10				
1,2,3,6,9-PeCDD 82291-34-7									6.24	10				
1,2,3,7,8-PeCDD 40321-76-4				(4.4E-10)- 9.48E-10	25	9,33			6.64	10				
1,2,3,7,9-PeCDD 71925-17-2									6.40	10				
1,2,3,8,9-PeCDD 71925-18-3														
1,2,4,6,7-PeCDD 82291-35-8														
1,2,4,6,8-PeCDD 71998-76-0														
1,2,4,6,9-PeCDD 82291-36-9									6.60	10				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m³/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,4,7,8-PeCDD 58802-08-7				(5.8E-10)	25	9			6.20	10				
1,2,4,7,9-PeCDD 82291-37-0														
1,2,4,8,9-PeCDD 82291-38-1														
Congener Group Average	(1.2E-04)	20	20	(7.3E-10)	25	20	(2.6E-06)	20	(6.6)	20	(5.7)	20		
Hexachlorodibenzo-p-dioxins(MW=390.87)														
1,2,3,4,6,7-HxCDD 58200-66-1														
1,2,3,4,6,8-HxCDD 58200-67-2									6.85	10				
1,2,3,4,6,9-HxCDD 58200-68-3														
1,2,3,4,7,8-HxCDD 39227-28-6	4.40E-06	20	6	(3.8E-11)-1.01E-10	25	9,33	(1.2E-05)	19	7.79-(11)	7,8,26	5.92	45	1.1E-04[c]	23
1,2,3,6,7,8-HxCDD 57653-85-7				(3.6E-11)	25	9								
1,2,3,6,7,9-HxCDD 64461-98-9									7.59	10				
1,2,3,6,8,9-HxCDD 58200-69-4									7.59	10				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,3,7,8,9-HxCDD 19408-74-3				(4.9E-11)	25	9								
1,2,4,6,7,9-HxCDD 39227-62-8				(5.1E-11)	25	9			6.85	10				
1,2,4,6,8,9-HxCDD 58802-09-8									6.85	10				
Congener Group Average	(4.4E-06)	20	20	(5.9E-11)	25	20	(1.2E-05)	20	(7.3)	20	(5.9)	20		
Heptachlorodibenzo-p-dioxins (MW=425.31)														
1,2,3,4,6,7,8-HpCDD 35822-46-9	2.40E-06	20	6	(5.6E-12)-3.21E-11	25	9,33	(7.5E-06)	19	8.20-(12)	7,8,26			1.53E-05[c]	23
1,2,3,4,6,7,9-HpCDD 58200-70-7														
Congener Group Average	(2.4E-06)	20	20	(3.2E-11)	25	20	(7.5E-06)	20	(8.2)	20				
Octachlorodibenzo-p-dioxin (MW=460.76)														
1,2,3,4,6,7,8,9-OCDD 3268-87-9	7.4E-08-4.00E-07	20-25	5,6,7	8.25E-13-6.54E-08	20-25	7,9, 33	(6.7E-06)	5	(7.5)-(13)	5,7,8,26 ,29			2.26E-05[c]	23
Tetrachlorodibenzofurans (MW=305.98)														
1,2,3,4-TCDF 30402-14-3				(3.1E-08)	25	21			6.17	10				
1,2,3,6-TCDF 83704-21-6									6 15	10				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m³/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,3,7-TCDF 83704-22-7				(3.2E-08)	25	21								
1,2,3,8-TCDF 62615-08-1				(2.1E-08)	25	21			6.15	10				
1,2,3,9-TCDF 83704-23-8									6.06	10				
1,2,4,6-TCDF 71998-73-7														
1,2,4,7-TCDF 83719-40-8														
1,2,4,8-TCDF 64126-87-0				(2.2E-08)	25	21			6.31	10				
1,2,4,9-TCDF 83704-24-9														
1,2,6,7-TCDF 83704-25-0				(2.0E-08)	25	21			6.25	10				
1,2,6,8-TCDF 83710-07-0														
1,2,6,9-TCDF 70648-18-9														
1,2,7,8-TCDF 58802-20-3				(1.8E-08)	25	21			6.23	10				
1,2,7,9-TCDF 83704-26-1				(2.5E-08)	25	21			6.25	10				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,8,9-TCDF 70648-22-5														
1,3,4,6-TCDF 83704-27-2									6.31	10				
1,3,4,7-TCDF 70648-16-7									6.23	10				
1,3,4,8-TCDF 92341-04-3									6.13	10				
1,3,4,9-TCDF 83704-28-3									5.89	10				
1,3,6,7-TCDF 57117-36-9				(2.8E-08)	25	21								
1,3,6,8-TCDF 71998-72-6				(2.7E-08)	25	21			6.37	10				
1,3,6,9-TCDF 83690-98-6														
1,3,7,8-TCDF 57117-35-8									6.34	10				
1,3,7,9-TCDF 64560-17-4				(1.9E-08)	25	21			6.34	10				
1,4,6,7-TCDF 66794-59-0				(2.6E-08)	25	21			6.15	10				
1,4,6,8-TCDF 82911-58-8														

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,4,6,9-TCDF 70648-19-0									5.60	10				
1,4,7,8-TCDF 83704-29-4														
1,6,7,8-TCDF 83704-33-0									6.17	10				
2,3,4,6-TCDF 83704-30-7				(4.0E-08)	25	21			6.11	10				
2,3,4,7-TCDF 83704-31-8				(2.9E-08)	25	21			6.06	10				
2,3,4,8-TCDF 83704-32-9				(2.8E-08)	25	21								
2,3,6,7-TCDF 57117-39-2				(2.1E-08)	25	21			6.31	10				
2,3,6,8-TCDF 57117-37-0				(2.0E-08)	25	21			6.73	10				
2,3,7,8-TCDF 51207-31-9	4.19E-04	22.7	11	8.96E-09- (1.5E-08)	25	21,33	(8.6E-06)	19	5.82- 6.53	8,10				
2,4,6,7-TCDF 57117-38-1				(3.3E-08)	25	21			6.25	10				
2,4,6,8-TCDF 58802-19-0				(2.0E-08)	25	21			6.17	10				
3,4,6,7-TCDF 57117-40-5														

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m³/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Congener Group Average	(4.2E-04)	22.7	20	(2.5E-08)	25	20	(8.6E-06)	20	(6.2)	20				
Pentachlorodibenzofurans (MW=340.42)														
1,2,3,4,6-PeCDF 83704-47-6				(2.7E-09)	25	21								
1,2,3,4,7-PeCDF 83704-48-7									6.53	10				
1,2,3,4,8-PeCDF 67517-48-0				(3.6E-09)	25	21			6.79	10				
1,2,3,4,9-PeCDF 83704-49-8														
1,2,3,6,7-PeCDF 57117-42-7				(2.2E-09)	25	21			6.26	10				
1,2,3,6,8-PeCDF 83704-51-2									6.33	10				
1,2,3,6,9-PeCDF 83704-52-3														
1,2,3,7,8-PeCDF 57117-41-6				(1.7E-09)- 2.72E-09	25	21,33			6.79	10				
1,2,3,7,9-PeCDF 83704-53-4														
1,2,3,8,9-PeCDF 83704-54-5														

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,4,6,7-PeCDF 83704-50-1				(3.5E-09)	25	21			6.27	10				
1,2,4,6,8-PeCDF 69698-57-3				(2.3E-09)	25	21			6.34	10				
1,2,4,6,9-PeCDF 70648-24-7									6.59	10				
1,2,4,7,8-PeCDF 58802-15-6				(1.5E-09)	25	21			6.26	10			1.30E-02[b]	25
1,2,4,7,9-PeCDF 71998-74-8				(2.6E-09)	25	21			6.19	10				
1,2,4,8,9-PeCDF 70648-23-6														
1,2,6,7,8-PeCDF 69433-00-7				(1.9E-09)	25	21			6.42	10				
1,2,6,7,9-PeCDF 70872-82-1									6.51	10				
1,3,4,6,7-PeCDF 83704-36-3				(2.7E-09)	25	21			6.19	10				
1,3,4,6,8-PeCDF 83704-55-6									6.24	10				
1,3,4,6,9-PeCDF 70648-15-6									6.34	10				
1,3,4,7,8-PeCDF 58802-16-7				(4.3E-09)	25	21								

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,3,4,7,9-PeCDF 70648-20-3									6.33	10				
1,3,6,7,8-PeCDF 70648-21-4														
1,4,6,7,8-PeCDF 83704-35-2									6.53	10				
2,3,4,6,7-PeCDF 57117-43-8				(2.4E-09)	25	21			6.47	10				
2,3,4,6,8-PeCDF 67481-22-5				(1.9E-09)	25	21			6.59	10				
2,3,4,7,8-PeCDF 57117-31-4	2.36E-04	22.7	11	(2.6E-09)-3.29E-09	25	21,33	(6.2E-06)	19	6.92	10				
Congener Group Average	(2.4E-04)	22.7	20	(2.7E-09)	25	20	(6.2E-06)	20	(6.4)	20				
Hexachlorodibenzofurans (MW = 374.87)														
1,2,3,4,6,7-HxCDF 79060-60-9				(2.4E-10)	25	21								
1,2,3,4,6,8-HxCDF 69698-60-8				(2.2E-10)	25	21								
1,2,3,4,6,9-HxCDF 91538-83-9				(4.1E-10)	25	21								
1,2,3,4,7,8-HxCDF 70648-26-9	8.25E-06	22.7	11	(2.4E-10)	25	21	(1.4E-05)	19					6.96E-04[b]	25

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
1,2,3,4,7,9-HxCDF 91538-84-0				(2.8E-10)	25	21								
1,2,3,4,8,9-HxCDF 92341-07-6														
1,2,3,6,7,8-HxCDF 57117-44-9	1.77E-05	22.7	11	(2.2E-10)	25	21	(6.1E-06)	19						
1,2,3,6,7,9-HxCDF 92341-06-5														
1,2,3,6,8,9-HxCDF 75198-38-8				(3.4E-10)	25	21								
1,2,3,7,8,9-HxCDF 72918-21-9				(1.8E-10)	25	21								
1,2,4,6,7,8-HxCDF 67562-40-7				(2.6E-10)	25	21								
1,2,4,6,7,9-HxCDF 75627-02-0				(5.7E-10)	25	21								
1,2,4,6,8,9-HxCDF 69698-59-5				(1.8E-10)	25	21								
1,3,4,6,7,8-HxCDF 71998-75-9				(2.3E-10)	25	21								
1,3,4,6,7,9-HxCDF 92341-05-4														
2,3,4,6,7,8-HxCDF 60851-34-5				(2.0E-10)	25	21							.	

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m^3/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Congener Group Average	(1.3E-05)	22.7	20	(2.8E-10)	25	20	(1.0E-05)	20						
Heptachlorodibenzofurans (MW=409.31)														
1,2,3,4,6,7,8-HpCDF 67562-39-4	1.35E-06	22.7	11	(3.5E-11)- 1.33E-10	25	21,33	(5.3E-05)	19	7.92	10				
1,2,3,4,6,7,9-HpCDF 70648-25-8														
1,2,3,4,6,8,9-HpCDF 69698-58-4				(5.8E-11)	25	21								
1,2,3,4,7,8,9-HpCDF 55673-89-7				(4.6E-11)- 1.07E-10	25	21,33								
Congener Group Average	(1.4E-06)	22.7	20	(9.9E-11)	25	20	(5.3E-05)	20	(7.9)	20				
Octachlorodibenzofurans (MW=444.76)														
1,2,3,4,6,7,8,9-OCDF 39001-02-0	(1.2E-06)	25	11	3.75E-12	25	21	(1.9E-06)	19	(7.0)- (13)	8,26,29				
Tetrachloro-PCB (MW=291.99)														
3,3',4,4'-TCB 32598-13-3	(1.6E-06) -(1.1E-02)	25	12,13,17, 28,35,38, 40,44	(7.5E-10) -1.37E-07	25	13,18	9.40E-05- (1.0E-04)	13,35,39	5.62- 6.21	8,15,31				
3,4,4',5-TCB 70362-50-4	8.43E-06- (2.9E-03)	25	17,41	(2.6E-10)- 2.80E-10	25	18,41	1.28E-04- (1.5E-04)	16,35,41	(6.4)	15				

Table A-1 (continued)

Chemical CAS No.	Water Solubility mg/l[a]	WS Temp.	WS Ref.	Vapor Pressure mm Hg[a]	VP Temp.	VP Ref.	Henry's Constant atm-m³/mol[a]	Henry's Constant Ref.	Log K_{ow}[a]	Log K_{ow} Ref.	Log K_{oc}[a]	Log K_{oc} Ref.	Photo Quantum Yield[a]	Photo Quant. Yield Ref.
Pentachloro-PCB (MW=326.44)														
2,3,3',4,4'-PeCB 32598-14-4	(1.9E-03)- (1.1E-02)	25	17,35,37	(3.7E-09)	25	18	(6.0E-05)- (9.9E-05)	16,35	(6.3)- (6.6)	15,37				
2,3,4,4',5-PeCB 74472-37-0	3.69E-06- (1.1E-02)	25	17,35,37, 41	5.96E-10- (2.1E-09)	25	18,41	6.9E-05- (1.4E-04)	16,35,41	(6.3)- (6.6)	15,37				
2,3',4,4',5-PeCB 31508-00-6	4.27E-06- (1.1E-02)	25	17,35,37, 41	8.45E-10- (2.7E-09)	25	18,41	8.5E-05- 4.0E-04	16,35,41, 43	(6.2)- 7.12	15,31,37	(5.7)	42		
3,3',4,4',5-PeCB 57465-28-8	(1.0E-03)	25	17	(2.9E-06)	25	18	(5.4E-05)- (8.2E-05)	16,35	(6.9)	15				
Hexachloro-PCB (MW=360.88)														
2,3,3',4,4',5-HxCB 38380-08-4	7.44E-07- (2.4E-03)	25	17,37,41	(1.4E-06)	25	18	(2.2E-05) -8.7E-04	16,35,43	(6.6)- (7.2)	14,15,37				
2,3,3',4,4',5'-HxCB 69782-90-7	(3.6E-04)	25	17	(1.2E-06)	25	18	(6.6E-05) -5.8E-04	16,35,43	7.16- (7.2)	14,15				
2,3',4,4',5,5'-HxCB 52663-72-6	(3.6E-04)- (2.4E-03)	25	17,37	(2.0E-06)	25	18	(1.1E-04)- (1.2E-04)	16,35	(6.6)- (7.3)	14,15,37				
3,3',4,4',5,5'-HxCB 32774-16-6	(3.6E-05)- (2.5E-03)	25	17,35,37	(1.5E-06)	25	20	(5.9E-05)- (6.5E-05)	16,35	(6.6)- 7.47	14,15,37				
Heptachloro-PCB (MW=396.33)														
2,3,3',4,4',5,5'-HpCB 39635-31-9	(4.5E-05)- (5.4E-04)	25	17,35,37	(3.0E-07)	25	18	(6.6E-05)	35	(7.0)- (7.7)	15,37				

Table A-1 (continued)

Footnote References

[a] Values are presented as they appeared in the referenced articles. Subcooled liquid values were converted to solid values (33). Values in () are calculated.
[b] Tested in solution of water:acetonitrile (1:1 v/v) at 313 nm.
[c] Tested in solution of water:acetonitrile (2:3 v/v) at 313 nm.
[d] Tested in vapor phase at 250-360 nm.

1. Marple et al. (1986a)
2. USEPA (1990)
3. Podoll et al. (1986)
4. Marple et al. (1986b)
5. Shiu et al. (1988)
6. Friesen et al. (1985)
7. Webster et al. (1985)
8. Burkhard and Kuehl (1986)
9. Rordorf (1987)
10. Sijm et al. (1989)
11. Friesen et al. (1990)
12. Dickhut et al. (1986)
13. Dunnivant and Elzerman (1988)
14. Risby et al. (1990)
15. Hawker and Connell (1988)
16. Sabljic and Gunsten (1989)
17. Abramowitz and Yalkowsky (1990)
18. Foreman and Bidleman (1985)
19. Calculated by the VP/WS ratio technique
20. Average of all literature values (measured and calculated) within a congener group
21. Rordorf (1989)
22. Dulin et al. (1986)
23. Choudhry and Webster (1987)
24. Choudhry and Webster (1989)
25. Choudhry et al. (1990)
26. Sarna et al. (1984)
27. Adams and Blaine (1986)
28. Mackay et al. (1980)
29. Doucette and Andren (1988a)
30. Orth et al. (1989)
31. Rapaport and Eisenreich (1984)
32. Lodge and Cook (1989)
33. Eitzer and Hites (1988)
34. Rordorf (1985)
35. Dunnivant et al. (1992)
36. Lodge (1989)
37. Patil (1991)
38. Nirmalakhandan and Speece (1989)
39. Dunnivant et al. (1988)
40. Opperhuizen et al. (1988)
41. Murphy et al. (1987)
42. EPRI (1990)
43. Murphy et al. (1983)
44. Yalkowsky et al. (1983)
45. Webster et al. (1986)
46. Doucette and Andren (1988b)
47. Walters and Guiseppi-Elie (1988)
48. Jackson et al. (1986)
49. Puri et al. (1989)
50. Marple et al. (1987)

Table A-2. Rankings for the P-Chem Property Literature

Reference Number	Ranking[a]					
	Water Solubility	Vapor Pressure	Henry's Constant	Log K_{ow}	Log K_{oc}	Photo Quantum Yield
1	2					
3		2	4			
4				1		
5	2		4	1		
6	2					
7	2	2	2	4		
8				4		
9		2 & 5				
10				1 & 2		
11	2					
12	1					
13	1	4	2			
14				3		
15				2 & 5		
16			5			
17	5					
18		5				
19			5			
20	5	5	5	5	5	
21		2 & 5				
22						2
23						2
24						2
25						2
26				5		

Table A-2 (continued)

Reference Number	Ranking[a]					
	Water Solubility	Vapor Pressure	Henry's Constant	Log K_{ow}	Log K_{oc}	Photo Quantum Yield
27	2					
28	5					
29				5		
30						2
31				4		
32					1	
33		4				
34		4				
35	5		5			
36	2					
37	5			5		
38	5					
39			2			
40	2					
41	2	2	4			
42					4	
43			4			
44	5					
45					2	
46	2					
47					1	
48					1	
49					2	
50	1			1	1	

Table A-2 (continued)

Footnote References

[a] P-chem properties with two ranks indicates that some of the values for the chemicals in the reference had been verified by another laboratory, and some values have not been verified yet. It also indicates that more than one methodology may have been used in the reference to determine the p-chem property.

1. Marple et al. (1986a)
3. Podoll et al. (1986)
4. Marple et al. (1986b)
5. Shiu et al. (1988)
6. Friesen et al. (1985)
7. Webster et al. (1985)
8. Burkhard and Kuehl (1986)
9. Rordorf (1987)
10. Sijm et al. (1989)
11. Friesen et al. (1990)
12. Dickhut et al. (1986)
13. Dunnivant and Elzerman (1988)
14. Risby et al. (1990)
15. Hawker and Connell (1988)
16. Sabljic and Gunsten (1989)
17. Abramowitz and Yalkowsky (1990)
18. Foreman and Bidleman (1985)
19. Calculated by the VP/WS ratio technique
20. Average of all literature values (measured and calculated) within a congener group.
21. Rordorf (1989)
22. Dulin et al. (1986)
23. Choudhry and Webster (1987)
24. Choudhry and Webster (1989)
25. Choudhry et al. (1990)
26. Sarna et al. (1984)
27. Adams and Blaine (1986)
28. Mackay et al. (1980)
29. Doucette and Andren (1988)
30. Orth et al. (1989)
31. Rapaport and Eisenreich (1984)
32. Lodge and Cook (1989)
33. Eitzer and Hites (1988)
34. Rordorf (1985)
35. Dunnivant et al. (1992)
36. Lodge (1989)
37. Patil (1991)
38. Nirmalakhandan and Speece (1989)
39. Dunnivant et al. (1988)
40. Opperhuizen et al. (1988)
41. Murphy et al. (1987)
42. EPRI (1990)
43. Murphy et al. (1983)
44. Yalkowsky et al. (1983)
45. Webster et al. (1986)
46. Doucette and Andren (1988)
47. Walters and Guiseppi-Elie (1988)
48. Jackson et al. (1986)
49. Puri et al. (1989)
50. Marple et al. (1987)

APPENDIX B. ENVIRONMENTAL CONCENTRATIONS

The tables in this appendix are discussed in Chapter 4. References listed at the end of each table are included in the reference list at the end of Chapter 4. Following are the tables included in this Appendix:

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Table B-1. Environmental Levels of Dioxins in Soil (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzo-p-dioxins (MW=321.98)									
2,3,7,8-TCDD	77	NR	ND-2.1	<0.5	British Isles	Background	NR	11	
	3	0	ND(0.2-2.0)	NA	Various parts of Europe	Rural	NR	10	
	2	2	2.4-0.84	1.62	Various parts of Europe	Industrial	NR	10	
	23	23	10-36000	2133	Midland, MI	Industrial		1	
	62	59	ND-270	55	Midland, MI	Residential		1	
	13	1	ND-2	<1	Henry, IL	Residential		1	
	22	6	ND-5	1	Middletown, OH	Residential		1	
	4	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	2	Finland	Industrial		2	
	33	33	41-52000	4300	Midland, MI	Industrial		3	
	11	9	ND-590	145	Midland, MI	Industrial		3	
	20	13	ND-9.4	2	US	Industrial		3	Urban area
	8	8	0.6-3.1	2	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
	12	12	1-7	3	England	Residential		7	Rural
	19	6	ND-4.2	1	England	Urban		8	
TCDDs	1	1	3.2	3.2	Various parts of Europe	Rural		10	
	77	NR	ND-69	9.4	British Isles	Background	NR	11	
	NR	NR	200	NR	Muggenburger st. Hamburg,Germany	Industrial	1985	12	Maximum contents reported
	NR	NR	2.8	NR	Kirchsteinbek, Hamburg,Germany	Industrial	1985	12	Maximum contents reported
	NR	NR	0.9	NR	Ochsenwerder Landscheideweg, Hamburg,Germany	Contaminated site	1985	12	Maximum contents reported
	NR	NR	874	NR	Moorefleeter Brack Hamburg,Germany	Contaminated site	1985	12	Maximum contents reported

Table B-1. Environmental Levels of Dioxins in Soils (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
TCDDs (continued)	47	11	ND-430	40.3	Ontario and U.S. Midwestern States.	Urban		13	
	2	2	11.2-55.5	33.4	Various parts of Europe	Industrial		10	
	1	1	320	320	Midland, MI	Industrial		1	
	7	5	ND-290	109	Midland, MI	Residential		1	
	5	0	ND(1.0)	NA	Middletown, OH	Residential		1	
	3	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	89	Finland	Industrial		2	
	11	NR	ND-7	<1	Canada			4	Near Incinerator
	12	NR	ND-430	69	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-1200	69	Canada	Urban		4	
	8	8	37-217	98	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Agriculture		6	
	12	12	17-120	42	England	Residential		7	Rural
	19	19	9-160	65	England	Urban		8	
Pentachlorodibenzo-p-dioxins (MW = 356.42)									
1,2,3,7,8-PeCDD	NR	NR	NR	15	Finland	Industrial		2	
	8	8	2.6-18.3	10	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
	19	7	ND-11	2	England	Urban		8	
	77	NR	ND-2.4	<0.5	British Isles	Background	NR	11	
PeCDDs	1	1	4.6	4.6	various parts of Europe	Rural		10	
	2	2	220-270	245	various parts of Europe	Industrial		10	
	77	NR	ND-46	6.6	British Isles	Background	NR	11	
	47	7	ND-580	38.4	Ontario and U.S. Midwestern States.	Urban		13	

Table B-1. Environmental Levels of Dioxins in Soils (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
PeCDDs (continued)	1	1	240	NA	Midland, MI	Industrial		1	
	6	2	ND-120	37	Midland, MI	Residential		1	
	5	0	ND(1.0)	NA	Middletown, OH	Residential		1	
	3	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	900	Finland	Industrial		2	
	11	NR	ND-580	53	Canada			4	Near Incinerator
	12	NR	ND-540	81	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-130	23	Canada	Urban		4	
	8	8	46-476	159	Sweden	Urban		5	Near Stockholm
	4	1	ND-38	10	Elk River, MN	Rural		6	Agriculture
	12	12	4-50	20	England	Residential		7	Rural
	19	19	6-190	69	England	Urban		8	
	13	13	33.7-1264	302	Salzburg, Austria	Urban	90-91	14	
	6	6	7.1-184	49.9	Salzburg, Austria	Rural	90-91	14	
	5	5	92.2-455	181	Salzburg, Austria	Industrial	90-91	14	
Hexachlorodibenzo-p-dioxins (MW=390.87)									
1,2,3,4,7,8-HxCDD	NR	NR	NR	<2	Finland	Industrial		2	
	8	8	4.3-8.0	6	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
1,2,3,6,7,8-HxCDD	NR	NR	NR	2100	Finland	Industrial		2	
	8	8	3.3-32.2	12	Sweden	Urban		5	Near Stockholm
	4	1	ND-14	4	Elk River, MN	Rural		6	AGriculture
1,2,3,7,8,9-HxCDD	NR	NR	NR	700	Finland	Industrial		2	
	8	8	1.6-16.6	8	Sweden	Urban		5	Near Stockholm
	4	2	ND-9.9	9	Elk River, MN	Rural		6	Agriculture

Table B-1. Environmental Levels of Dioxins in Soils (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HxCDDs	1	1	4.7	4.7	Various parts of Europe	Rural		10	
	2	2	200-330	265	Various parts of Europe	Industrial		10	
	77	NR	2.8-165	38	British Isles	Background	NR	11	
	47	13	ND-410	38.12	Ontario and U.S. Midwestern States.	Urban		13	
	20	8	ND-240	44.1	Canada and U.S.A.	Industrial		13	
	1	1	4000	4000	Midland, MI	Industrial		1	
	7	5	ND-410	172	Midland, MI	Residential		1	
	5	1	ND-72	14	Middletown, OH	Residential		1	
	3	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	7200	Finland	Industrial		2	
	11	NA	ND-170	15	Canada			4	Near Incinerator
	12	NA	ND-70	9	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	0	ND(55)	NA	Canada	Urban		4	
	8	8	43-349	156	Sweden	Urban		5	Near Stockholm
	4	4	12-99	48	Elk River, MN	Rural		6	Agriculture
	12	12	8-43	23	England	Residential		7	Rural
	19	19	23-340	154	England	Urban		8	
Heptachlorodibenzo-p-dioxins (MW = 425.31)									
1,2,3,4,6,7,8-HpCDD	NR	NR	NR	4700	Finland	Industrial		2	
	8	8	43-492	144	Sweden	Urban		5	Near Stockholm
	4	4	37-360	194	Elk River, MN	Rural		6	Agriculture
1,2,3,4,6,7,9-HpCDD	NR	NR	NR	7100	Finland	Industrial		2	
HpCDDs	3	1	ND-17	9.0	Various parts of Europe	Rural		10	
	2	2	370-1600	985	Various parts of Europe	Industrial		10	
	77	NR	7.5-234	66	British Isles	Background	NR	11	
	30	3	ND-91	5.4	Ontario and U.S. Midwestern States.	Rural		13	
	47	25	ND-2400	212	Ontario and U.S. Midwestern States.	Urban		13	
	20	19	ND-5000	1197	Canada and U.S.A.	Industrial		13	

Table B-1. Environmental Levels of Dioxins in Soils (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HpCDDs (continued)	1	1	75000	75000	Midland, MI	Industrial		1	
	7	7	150-2400	930	Midland, MI	Residential		1	
	5	5	23-200	113	Middletown, OH	Residential		1	
	3	3	25-91	54	MN	Pristine		1	
	11	NR	ND-390	90	Canada			4	Near Incinerator
	12	NR	ND-300	43	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-1100	93	Canada	Urban		4	
	8	8	83-904	277	Sweden	Urban		5	Near Stockholm
	4	4	62-640	346	Elk River, MN	Rural		6	Agriculture
	12	12	20-130	64	England	Residential		7	Rural
	19	19	77-5500	817	England	Urban		8	
Octachlorodibenzo-p-dioxin (MW=460.76)									
1,2,3,4,6,7,8,9-OCDD	1	1	14	14	Various parts of Europe	Rural		10	
	2	2	140-160	160	Various parts of Europe	Industrial		10	
	77	NR	29-832	191	British Isles	Background	NR	11	
	30	17	44-810	67.33	Ontario and U.S. Midwestern States.	Rural		13	
	47	38	ND-12000	1599	Ontario and U.S. Midwestern States.	Urban		13	
	20	20	15-26000	3442	Canada and U.S.A.	Industrial		13	
	1	1	375000	375000	Midland, MI	Industrial		1	
	7	7	330-12000	4473	Midland, MI	Residential		1	
	5	5	170-10600	2418	Middletown, OH	Residential		1	
	3	3	25-91	54	MN	Pristine		1	
	NR	NR	NR	6200	Finland	Industrial		2	
	11	NR	ND-3500	663	Canada			4	Near Incinerator
	12	NR	ND-1500	570	Canada			4	Near Incinerator
	53	NR	ND-100	31	Canada	Rural		4	
	29	NR	ND-16000	2464	Canada	Urban		4	
	8	8	113-2659	687	Sweden	Urban		5	Near Stockholm
	4	4	340-3300	1655	Elk River, MN	Rural		6	Agriculture

Table B-1. Environmental Levels of Dioxins in Soils (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD	12	12	20-150	58	England	Residential		7	Rural
(continued)	19	19	176-99000	9980	England	Urban		8	

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = Not applicable;
ND = Non-detect;
NR = Not reported;
Detection limits varied by study and as was different for different compounds, but generally were 1 to 5 ng/kg (ppt). Descriptions provided were those given by reference or surmised from study description when not given.

Sources:

1. EPA (1985)
2. Kitunen and Salkinoja-Salonen (1990).
3. Nestrick, et al. (1986).
4. Pearson, et al. (1990).
5. Broman, et al. (1990).
6. Reed, et al. (1990).
7. Stenhouse and Badsha (1990).
8. Creaser, et al. (1990)
10. Rappe and Kjeller (1987)
11. Creaser, et al. (1989)
12. Sievers and Friesel (1989)
13. Birmingham (1990)
14. Boos, et al. (1992)

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzofurans (MW=305.98)									
2,3,7,8-TCDF	2	2	27-450	238	Midland, MI	Industrial		1	
	8	3	ND-15	5	Midland, MI	Residential		1	
	5	2	ND-6	2	Middletown, OH	Residential		1	
	3	0	ND(1.0	NA	MN	Pristine		1	
	NR	NR	NR	<2	Finland	Industrial		2	
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
	12	12	3-50	17	England	Residential		7	Rural
2,3,4,8/2,3,7,8-TCDF	8	8	8.4-57.5	22	Sweden	Urban		5	Near Stockholm
TCDFs	3	3	7.7-11	9.3	Various parts of Europe	Rural		10	
	2	2	320-370	345	Various parts of Europe	Industrial		10	
	77	NR	ND-237	25	British Isles	Background		11	
	47	13	ND-120	42.92	Ontario and U.S. Midwestern states	Urban		13	
	20	3	ND-1850	1017	Ontario and U.S. Midwestern states	Industrial		13	
	1	0	ND(1.0)	NA	Midland, MI	Residential		1	
	1	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	300	Finland	Industrial		2	
	11	NR	ND-71	10	Canada			4	Near Incinerator
	12	0	ND(55)	NA	Canada			4	Near Incinerator
	53	1	ND-280	NA	Canada	Rural		4	
	29	NR	ND-120	15	Canada	Urban		4	
	8	8	109-454	237	Sweden	Urban		5	Near Stockholm
	4	1	ND-1.2	<1	Elk River, MN	Rural		6	Agriculture
	12	12	20-300	102	England	Residential		7	Rural

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
TCDFs (continued)	19	19	29-950	232	England	Urban		8	
Pentachlorodibenzofurans (MW = 340.42)									
1,2,3,7,8-PeCDF	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
	12	12	1-10	4	England	Residential		7	Rural
2,3,4,7,8-PeCDF	NR	NR	NR	580	Finland	Industrial		2	
	8	8	3.1-26.5	13	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
	12	12	1-5	2	England	Residential		7	Rural
1,2,3,7,8/1,2,3,4,8-PeCDF	NR	NR	NR	82	Finland	Industrial		2	
	8	8	7.4-32.1	16	Sweden	Urban		5	Near Stockholm
PeCDFs	3	3	6.7-14	11.2	Various parts of Europe	Rural		10	
	77	NR	ND-185	23	British Isles	Background		11	
	47	4	ND-110	41.5	Ontario and U.S. Midwestern states	Urban		13	
	20	5	ND-285	86	Ontario and U.S. Midwestern states	Industrial		13	
	2	2	200-450	325	Various parts of Europe	Industrial		10	
	1	1	900	900	Midland, MI	Industrial		1	
	8	2	ND-110	19	Midland, MI	Residential		1	
	5	0	ND	NA	Middletown, OH	Residential		1	
	NR	NR	NR	27000	Finland	Industrial		2	
	11	0	ND(55)	NA	Canada			4	Near Incinerator
	12	0	ND(55)	NA	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-160	35	Canada	Urban		4	

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
PeCDFs (continued)	8	8	36-457	149	Sweden	Urban		5	Near Stockholm
	4	3	18-45	35	Elk River, MN	Rural		6	Agriculture
	12	12	6-70	31	England	Residential		7	Rural
	19	19	19-830	189	England	Urban		8	
	13	13	45.6-261	115	Salzburg, Austria	Urban	90-91	14	
	6	6	12.0-77.7	46.5	Salzburg, Austria	Rural	90-91	14	
	5	5	53-355	182	Salzburg, Austria	Industrial	90-91	14	
Hexachlorodibenzofurans (MW = 374.87)									
1,2,3,4,7,8/1,2,3,4,7,9-HxCDF	NR	NR	NR	920	Finland	Industrial		2	
	8	8	7.8-29.1	16	Sweden	Urban		5	Near Stockholm
1,2,3,4,7,8-HxCDF	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
1,2,3,6,7,8-HxCDF	NR	NR	NR	<2	Finland	Industrial		2	
	8	8	7.7-28.9	14	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
1,2,3,7,8,9-HxCDF	NR	NR	NR	<2	Finland	Industrial		2	
	8	8	0.5-3.8	1	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
2,3,4,6,7,8-HxCDF	NR	NR	NR	<2	Finland	Industrial		2	
	4	1	ND-7.1	2	Elk River, MN	Rural		6	Agriculture
HxCDFs	3	3	11-16	13	Various parts of Europe	Rural		10	
	77	NR	4.3-212	41	British Isles	Background		11	
	47	6	ND-260	94.8	Ontario and U.S. Midwestern states	Urban		13	
	20	7	ND-420	178	Ontario and U.S. Midwestern states	Industrial		13	

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HxCDFs (continued)	2	2	270-1900	1085	Various parts of Europe	Industrial		10	
	1	1	15400	15400	Midland, MI	Industrial		1	
	8	3	64-260	62	Midland, MI	Residential		1	
	5	0	ND(1.0)	NA	Middletown, OH	Residential		1	
	3	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	7200	Finland	Industrial		2	
	11	0	ND(55)	NA	Canada			4	Near Incinerator
	12	0	ND(55)	NA	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-120	9	Canada	Urban		4	
	8	8	53-308	145	Sweden	Urban		5	Near Stockholm
	4	4	7-150	66	Elk River, MN	Rural		6	Agriculture
	12	12	6-50	24	England	Residential		7	Rural
	19	19	17-660	156	England	Urban		8	
Heptachlorodibenzofurans (MW = 409.31)									
1,2,3,4,6,7,8-HpCDF	NR	NR	NR	4700	Finland	Industrial		2	
	8	8	31-134	73	Sweden	Urban		5	Near Stockholm
	4	4	11-80	47	Elk River, MN	Rural		6	Agriculture
1,2,3,4,7,8,9-HpCDF	NR	NR	NR	<5	Finland	Industrial		2	
	8	8	1.0-6.3	3	Sweden	Urban		5	Near Stockholm
	4	0	ND(3.75)	NA	Elk River, MN	Rural		6	Agriculture
HpCDFs	3	3	14-22	18	Various parts of Europe	Rural		10	
	2	2	260-4500	2380	Various parts of Europe	Industrial		10	
	77	NR	1.5-138	26	British Isles	Background		11	

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HpCDFs (continued)	47	10	ND-120	283	Ontario and U.S. Midwestern states	Urban		13	
	20	15	ND-3750	733	Ontario and U.S. Midwestern states	Industrial		13	
	1	1	75000	75000	Midland, MI	Industrial		1	
	8	6	ND-820	300	Midland, MI	Residential		1	
	5	1	ND-43	9	Middletown, OH	Residential		1	
	3	0	ND(1.0)	NA	MN	Pristine		1	
	11	NR	ND-180	30	Canada			4	Near Incinerator
	12	0	ND(55)	NA	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-410	29	Canada	Urban		4	
	8	8	31-187	81	Sweden	Urban		5	Near Stockholm
	4	4	30-260	100	Elk River, MN	Rural		6	Agriculture
	12	12	4-59	20	England	Residential		7	Rural
	19	19	16-458	152	England	Urban		8	
Octachlorodibenzofurans (MW = 444.76)									
1,2,3,4,6,7,8,9-OCDF	1	1	5.7	5.7	Various parts of Europe	Rural		10	
	77	NR	ND-144	27	British Isles	Background		11	
	47	15	ND-660	185	Canada and USA	Urban		13	
	20	15	ND-5200	843	Canada and USA	Industrial		13	
	2	2	68-71	69.5	Various parts of Europe	Industrial		10	
	1	1	8600	8600	Midland, MI	Industrial		1	
	8	6	ND-660	240	Midland, MI	Residential		1	
	5	1	ND-50	10	Middletown, OH	Residential		1	

Table B-2. Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDF (continued)	3	0	ND(1.0)	NA	MN	Pristine		1	
	NR	NR	NR	3000	Finland	Industrial		2	
	11	NR	ND-33	4	Canada			4	Near Incinerator
	12	NR	ND-230	43	Canada			4	Near Incinerator
	53	0	ND(55)	NA	Canada	Rural		4	
	29	NR	ND-600	50	Canada	Urban		4	
	8	8	2.9-19.0	8	Sweden	Urban		5	Near Stockholm
	4	3	60-270	113	Elk River, MN	Rural		6	Agriculture
	12	12	10-90	30	England	Residential		7	Rural
	19	19	7-1100	196	England	Urban		8	

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = Not available;
NR = Not reported;
ND = Non-detect.
Detection limits varied by study and were different for different compounds, but generally were 1 to 5 ng/kg (ppt). Descriptions provided were those given by reference or surmised from study description when not given.

Sources:
1. EPA (1985)
2. Kitunen and Salkinoja-Salonen (1990.
3. Nestrick, et al. (1986).
4. Pearson, et al. (1990).
5. Broman, et al. (1990).
6. Reed, et al. (1990).
7. Stenhouse and Badaha (1990).
8. Creaser, et al. (1990)
10. Rappe and Kjeller (1987)
11. Creaser, et al. (1989)
12. Sievers and Friesel (1989)
13. Birmingham (1990)
14. Boos, et al. (1992)

Table B-3. Environmental Levels of Dioxins in Water (ppq)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Samp. year	Ref. no.	Comments
Tetrachlorodibenzo-p-dioxins (MW=321.98)									
2,3,7,8-TCDD	1	0	ND(0.7)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	0	ND(.02-.024)	NA	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
TCDDs	185	1	ND-40	2.70	Ontario, Canada	NR	83-89	1	raw surface drinking water
	22	0	ND(.4-2.6)	NA	New York State	NR	86-88	2	treated surface drinking water
	1	1	1.7	1.7	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.05-.084	.067	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Pentachlorodibenzo-p-dioxins (MW=356.42)									
1,2,3,7,8-PeCDD	1	0	ND(1.0)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	0	ND(.025-.039)	NA	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
PeCDDs	1	0	ND(1.0)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(1.2-7.4)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.067-.12	.094	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Hexachlorodibenzo-p-dioxins (MW=390.87)									
1,2,3,4,7,8-HxCDD	1	0	ND(1.8)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	1	ND-.054	.027	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
1,2,3,6,7,8-HxCDD	1	0	ND(1.5)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	1	ND-.12	.06	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
1,2,3,7,8,9-HxCDD	1	0	ND(1.5)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	1	ND-.075	.038	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water

Table B-3. Environmental Levels of Dioxins in Water (ppq) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Samp. year	Ref. no.	Comments
HxCDDs	1	0	ND(1.5)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(.4-4.7)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.13-.67	.4	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Heptachlorodibenzo-p-dioxins (MW = 425.31)									
1,2,3,4,6,7,8-HpCDD	1	0	ND(2.8)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.15-.30	.22	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
HpCDDs	1	0	ND(2.8)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(.4-6.8)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.17-.64	.40	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Octachlorodibenzo-p-dioxin (MW = 460.76)									
1,2,3,4,6,7,8,9-OCDD	185	32	ND-175	10.6	Ontario, Canada	NR	83-89	1	raw surface drinking water
	214	4	ND-46	3.16	Ontario, Canada	NR	83-89	1	treated surface drinking water

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, one-half the limit of detection was used in non-detects. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).
NA = not applicable;
ND = non-detected (limit of detection);
NR = not reported;
Descriptions provided were those given by reference or surmised from study description when not given.

Sources: 1. Jobb, et al. (1990)
2. Meyer, et al. (1989)
3. Rappe, et al. (1989b)

Table B-4. Environmental Levels of Dibenzofurans in Water (ppq)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Samp. year	Ref. no.	Comments
Tetrachlorodibenzofurans (MW=305.98)									
2,3,7,8-TCDF	2	2	.022-.026	.024	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
	1	0	ND(0.7)	NA	Lockport, New York	NR	88	2	raw surface drinking water
TCDFs	22	1	ND-2.6	0.12	New York State	NR	86-88	2	treated surface drinking water
	1	1	18	18	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.21-.23	0.22	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Pentachlorodibenzofurans (MW=340.42)									
1,2,3,7,8-PeCDF	1	1	2.0	2.0	Lockport, New York	NR	88	2	raw surface drinking water
2,3,4,7,8-PeCDF	2	2	.014-.019	.016	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
	1	0	ND(1.0)	NA	Lockport, New York	NR	88	2	raw surface drinking water
1,2,3,4,8/1,2,3,7,8-PeCDF	2	2	.013-.025	.019	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
PeCDFs	1	1	27	27	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(0.3-4.0)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.13-.21	.17	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Hexachlorodibenzofurans (MW=374.87)									
1,2,3,4,7,8-HxCDF	1	1	39	39	Lockport, New York	NR	88	2	raw surface drinking water
1,2,3,6,7,8-HxCDF	1	1	9.2	9.2	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.019-.025	.022	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
2,3,4,6,7,8-HxCDF	1	0	ND(1.3)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	1	ND-.027	.014	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
1,2,3,7,8,9-HxCDF	1	0	ND(1.2)	NA	Lockport, New York	NR	88	2	raw surface drinking water
	2	1	ND-.022	.011	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water

Table B-4. Environmental Levels of Dibenzofurans in Water (ppq) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,9/1,2,3,4,7,8-HxCDF	2	2	.021-.026	.024	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
HxCDFs	1	1	85	NA	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(.3-4.4)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.17-.19	.18	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Heptachlorodibenzofurans (MW=409.31)									
1,2,3,4,6,7,8-HpCDF	1	1	210	210	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.083-.13	.11	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
1,2,3,4,7,8,9-HpCDF	2	2	.03-.058	.044	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
HpCDFs	1	1	210	210	Lockport, New York	NR	88	2	raw surface drinking water
	22	0	ND(.8-6.6)	NA	New York State	NR	86-88	2	treated surface drinking water
	2	2	.18-.35	.26	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water
Octachlorodibenzofurans (MW=444.76)									
1,2,3,4,6,7,8,9-OCDF	22	2	ND-0.8	2.45	New York State	NR	86-88	2	treated surface drinking water
	1	1	230	230	Lockport, New York	NR	88	2	raw surface drinking water
	2	2	.15-.36	.26	Eman River, Sweden	PCB contaminated	NR	3	raw surface drinking water

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, one-half the detection limit was used for non-detects. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).
NA = not applicable;
ND = non-detected (limit of detection);
NR = not reported.
Descriptions provided were those given by reference or surmised from study description when not given.

Sources: 2. Meyer, et al. (1989) 3. Rappe, et al. (1989b)

Table B-5. Environmental Levels of Dioxins in Sediments (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments*
Tetrachlorodibenzo-p-dioxins (MW=321.98)										
2,3,7,8-TCDD	18	0	ND	NA	Dry	South Central Finland	Various	88/89	1	A,B
	9	8	ND-730	236	Dry	Newark, NJ	Industrial	85/86	2	0-2", A,C
	4	4	75-2500	1769	Dry	Newark, NJ	Industrial	85/86	2	2-4", A,C
	2	2	190-1200	695	Dry	Newark, NJ	Industrial	85/86	2	4-8", A,C
	1	1	680	680	Dry	Newark, NJ	Industrial	85/86	2	12-16", A,C
	1	1	150	150	Dry	Newark, NJ	Industrial	85/86	2	20-24", A,C
	2	2	660-1100	880	Dry	Newark, NJ	Industrial	85/86	2	24-28", A,C
	3	1	ND-7600	367	Dry	Newark, NJ	Industrial	85/86	2	28-32", A,C
	3	3	390-2900	1227	Dry	Newark, NJ	Industrial	85/86	2	32-36", A,C
	1	1	93	93	Dry	Newark, NJ	Industrial	85/86	2	40-44", A,C
	2	1	ND-7600	3800	Dry	Newark, NJ	Industrial	85/86	2	48-52", A,C
	1	1	21,000	21000	Dry	Newark, NJ	Industrial	85/86	2	108-111", A,C
	1	0	ND	NA	Dry	Long Island Sound	Reference Site	NR	4	A
	12	6	ND-57	13	Dry	New England	Industrial	NR	4	A/3 sites
	4	0	ND	NA	Dry	Seattle, WA	Industrial	NR	4	A
	4	0	ND	NA	NR	Central Minnesota	Rural	NR	5	A
	2	2	1.0-1.4	1.2	Dry	Baltic Sea	Reference Site	NR	13	A
	3	2	ND-2.4	1.5	NR	Stockholm Sweden	Various	NR	12	A
	4	4	1.9-26	9.6	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	1	ND-3	1.19	NR	Dala River, Sweden	Industrial	88	17	0-1 cm

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comment
2,3,7,8-TCDD (continued)	6	6	1.2-32	12.0	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	3	ND-110	28.1	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
	4	4	0.03-0.11	0.06	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-1 cm, E
	1	1	0.04	0.04	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E
	1	1	0.01	0.01	Dry	Fjord between Demark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	3.4-1,500	375	NR	Hamburg Germany	Urban	NR	15	
TCDDs	18	14	ND-1,400	372	Dry	South Central Finland	Various	88/89	1	AB
	1	1	26	26	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5 cm, A,D
	1	1	12	12	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6 cm, A,D
	1	0	ND	NA	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9 cm, A,D
	4	0	ND	NA	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	0	ND	NA	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	7	ND-44	17	NR	NY/Mass	NR	NR	10	A
	3	3	21-69	38	NR	Stockholm Sweden	Various	NR	12	A
	4	4	21-66	45	Dry	Iggesund Sweden	Industrial	NR	13	A/paper mill
	2	2	19-35	27	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	1.4-6.7	4.2	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-2 cm, E

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
TCDDs (continued)	1	1	13	13	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E
	1	1	5.0	5.0	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	80-1,700	564	NR	Hamburg Germany	Urban	NR	15	
Pentachlorodibenzo-p-dioxins (MW=356.42)										
1,2,3,7,8-PeCDD	4	3	ND-25	7.68	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	7.4-95	44.1	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	4	ND-100	49.6	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
PeCDDs	1	1	12	12	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5 cm, A,D
	1	1	11	11	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6 cm, A,D
	1	0	ND	NA	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9 cm, A,D
	4	0	ND	NA	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	0	ND	NA	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	7	ND-235	50	NR	NY/Mass	NR	NR	10	A
	3	3	86-230	138	NR	Stockholm Sweden	Various	NR	12	A
	4	4	52-500	209	Dry	Iggesund Sweden	Industrial	NR	13	A/paper mill
	2	2	52-100	76	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	1.7-41	19	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-2 cm, E

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
PeCDDs (continued)	1	1	6.6	6.6	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E
	1	1	15	15	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	260-2,700	1,112	NR	Hamburg Germany	Urban	NR	15	
Hexachlorodibenzo-p-dioxins (MW=390.87)										
1,2,3,4,7,8-HxCDD	4	3	ND-19	6.68	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	6.1-33	20.5	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	14-94	36.0	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
1,2,3,6,7,8-HxCDD	4	4	4.9-120	36.4	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	21-450	188	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	36-600	236	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
1,2,3,7,8,9-HxCDD	4	4	3.9-51	18.1	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	18-200	95.5	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	18-330	149	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
HxCDDs	1	1	10	10	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5 cm, A,D
	1	1	8	8	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6 cm, A,D
	1	0	ND	NA	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9 cm, A,D
	4	2	ND-14	5.2	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	6	ND-5,700	1,157	NR	Ontario Canada	Industrial	88	8	A/25 sites

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
HxCDDs (continued)	12	10	ND-1,335	399	NR	NY/Mass	NR	NR	10	A
	3	3	16-49	28	NR	Stockholm Sweden	Various	NR	12	A
	2	2	120-170	145	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	130-1,900	608	Dry	Iggesund Sweden	Industrial	NR	13	A/paper mill
	4	4	2.3-27.0	14	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-2 cm, E
	1	1	16	16	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E
	1	1	14	14	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	580-7,500	2,744	NR	Hamburg Germany	Urban	NR	15	
Heptachlorodibenzo-p-dioxins (MW=425.31)										
HpCDDs	4	4	7.3-110	71	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	20	ND-320,000	51,680	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	11	ND-18,950	4,168	NR	NY/Mass	NR	NR	10	A
	3	3	880-5,700	2,233	NR	Stockholm Sweden	Various	NR	12	A
	2	2	79-210	145	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	90-340	190	Dry	Iggesund Sweden	Industrial	NR	13	A/paper mill
	4	4	2.2-19	12.4	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-2 cm, E
	1	1	7.2	7.2	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments[a]
HpCDDs (continued)	1	1	7.1	7.1	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	1,300-8,600	4,040	NR	Hamburg Germany	Urban	NR	15	
Octachlorodibenzo-p-dioxin (MW=460.76)										
1,2,3,4,6,7,8,9-OCDD	18	3	ND-42	6.1	Dry	South Central Finland	Various	88/89	1	A,B
	9	9	3,100-14,000	8,100	Dry	Newark, NJ	Industrial	85/86	2	0-2", A,C
	4	4	5,300-23,000	14,100	Dry	Newark, NJ	Industrial	85/86	2	2-4", A,C
	2	2	10,000-31,000	20,500	Dry	Newark, NJ	Industrial	85/86	2	4-8", A,C
	1	1	7,500	7,500	Dry	Newark, NJ	Industrial	85/86	2	12-16", A,C
	1	1	5,900	5,900	Dry	Newark, NJ	Industrial	85/86	2	20-24", A,C
	2	2	11,000-19,000	15,000	Dry	Newark, NJ	Industrial	85/86	2	24-28", A,C
	2	2	5,500-22,000	13,800	Dry	Newark, NJ	Industrial	85/86	2	28-32", A,C
	3	3	5,600-42,000	17,800	Dry	Newark, NJ	Industrial	85/86	2	32-36", A,C
	1	1	5,500	5,500	Dry	Newark, NJ	Industrial	85/86	2	40-44", A,C
	2	2	4,400-24,000	14,200	Dry	Newark, NJ	Industrial	85/86	2	48-52", A,C
	1	1	38,000	38,000	Dry	Newark, NJ	Industrial	85/86	2	108-111", A,C
	1	1	560	560	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	0-0.5 cm, A,D
	1	1	390	390	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	5-6 cm, A,D
	1	1	54	54	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	8-9 cm, A,D

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	4	4	450-600	518	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	20	ND-980,000	141,420	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	12	1,990-15,500	8,201	NR	NY/Mass	NR	NR	10	A
	7	7	12-250	145	Dry	Jackfish Bay, Lake Superior	Various	NR	11	Papermill, atmospheric contamination
	3	3	260-3,100	1,290	NR	Stockholm Sweden	Various	NR	12	A
	2	2	89-250	170	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	96-330	194	Dry	Iggesund Sweden	Industrial	NR	13	A/paper mill
	4	4	180-16,830	5195	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	800-2200	1775	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	1320-6090	3040	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
	4	4	3.6-45	24	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	0-2 cm, E
	1	1	10	10	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	4-6 cm, E
	1	1	6.9	6.9	Dry	Fjord between Denmark, Sweden, and Norway	Industrial	87	14	9-13 cm, E
	5	5	2,800-15,000	7,560	NR	Hamburg Germany	Urban	NR	15	

Table B-5. Environmental Levels of Dioxins in Sediments (ppt) (continued)

[a] Key: A LOD (Ref 1) = 20 to 50 ppt, LOD (Ref 2) = 22 to 60 ppt, LOD (Ref 3) = 0.4 ppt, LOD (Ref 4) = 0.7 to 12.0 ppt, LOD (Ref 5) = 0.61 to 4.1 ppt, LOD (Ref 8) = 10 to 500 ppt, LOD (Ref 10) = 3 ppt, LOD (Ref 12) = 1 to 20 ppt, LOD (Ref 13) = 1 to 6.6 ppt.

B Dry surface sediments from 18 lakes.

C Industry produced 2,4,5-Trichlorophenate (2,4,5-T precursor).

D No anthropogenic inputs into drainage basin--only atmospheric sources into lake.

E Mg-Production Facility.

Notes

NR = Not Reported
NA = Not Applicable
ND = Not Detected
ppt = Parts per trillion

Sources:

1. Koistinen et al. (1990)
2. Bopp et al. (1991)
3. Czuczwa et al. (1984)
4. Norwood et al. (1989)
5. Reed et al. (1990)
6. Sonzongi et al. (1991)
7. Oliver and Nilmi (1988)
8. McKee et al. (1990)
9. Huckins et al. (1988)
10. Petty et al. (1982)
11. Sherman et al. (1990)
12. Rappe and Kjeller (1987)
13. Rappe et al. (1989a)
14. Oehme et al. (1989)
15. Gotz and Schumacher (1990)
16. Smith et al. (1990)
17. Kjeller et al. (1990)

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments[a]
Tetrachlorodibenzofurans (MW=305.98)										
2,3,7,8-TCDF	18	0	ND(20-50)	NA	Dry	South Central Finland	Various	88/89	1	A,B
	9	9	24-490	232	Dry	Newark, NJ	Industrial	85/86	2	0-2", A,C
	4	4	150-1,400	855	Dry	Newark, NJ	Industrial	85/86	2	2-4", A,C
	2	2	580-1,200	890	Dry	Newark, NJ	Industrial	85/86	2	4-8", A,C
	1	1	370	370	Dry	Newark, NJ	Industrial	85/86	2	12-16", A,C
	1	1	300	300	Dry	Newark, NJ	Industrial	85/86	2	20-24", A,C
	2	2	300-390	345	Dry	Newark, NJ	Industrial	85/86	2	24-28", A,C
	3	2	ND-530	243	Dry	Newark, NJ	Industrial	85/86	2	28-32", A,C
	3	3	190-730	370	Dry	Newark, NJ	Industrial	85/86	2	32-36", A,C
	1	1	140	140	Dry	Newark, NJ	Industrial	85/86	2	40-44", A,C
	2	2	80-3,100	1,590	Dry	Newark, NJ	Industrial	85/86	2	48-52", A,C
	1	1	4,500	4,500	Dry	Newark, NJ	Industrial	85/86	2	108-111", A,C
	1	1	15	15	Dry	Long Island Sound	Reference Site	NR	4	A
	12	12	8.8-1,400	566	Dry	New England	Industrial	NR	4	A/3 sites
	4	0	ND(0.7-12)	NA	Dry	Seattle, WA	Industrial	NR	4	A
	4	1	ND-0.31	0.08	NR	Central Minnesota	Rural	NR	5	A/4 sites
	2	2	8.3-14	11	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	11-210	72	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	4	4.9-170	46.5	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	41-320	176	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments*
2,3,7,8-TCDF (continued)	5	5	54-810	241	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
	4	4	0.7-9.6	5.2	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E
	1	1	13	13	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	5.2	5.2	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
TCDFs	1	1	15	15	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	0-0.5cm, A,D
	1	1	18	18	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	5-6cm, A,D
	1	0	ND(0.4)	NA	Dry	Siskiwit Lake, Isle Royale, Lake Superior	Pristine	NR	3	8-9cm, A,D
	4	2	ND-0.54	0.21	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	0	ND(10-700)	NA	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	11	ND-200	58	NR	NY/MASS	NR	NR	10	A
	7	7	2.4-6,223	1,260	Dry	Jackfish Bay, Lake Superior	Various	NR	11	Papermill/ atmospheric contamination
	3	3	120-290	187	NR	Stockholm Sweden	Various	NR	12	A
	2	2	87-130	109	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	79-360	180	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	4	6.7-54	30	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments*
TCDFs (continued)	1	1	63	63	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	23	23	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
	5	5	170-1070	526	NR	Hamburg Germany	Urban	NR	15	
Pentachlorodibenzofurans (MW=340.42)										
1,2,3,7,8-PeCDF	4	4	5.6-110	34.4	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	27-120	74.3	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	50-300	120	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
2,3,4,7,8-PeCDF	4	4	7.8-99	34.7	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	25-110	74.2	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	36-250	108	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
PeCDFs	1	1	5.0	5.0	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5cm A,D
	1	1	2.0	2.0	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6cm A,D
	1	0	ND(0.4)	NA	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9cm A,D
	4	2	ND-25	7.4	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	0	ND(10-700)	NA	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	9	ND-193	64	NR	NY/MASS	NR	NR	10	A
	3	3	130-260	177	NR	Stockholm Sweden	Various	NR	12	A
	2	2	66-125	96	Dry	Baltic Sea	Reference Site	NR	13	A

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments[a]
PeCDFs (continued)	4	4	48-58	55	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	4	7.7-81	47	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E
	1	1	24	24	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	44	44	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
	5	5	1,300-5,200	2,980	NR	Hamburg Germany	Urban	NR	15	
Hexachlorodibenzofurans (MW = 374.87)										
1,2,3,4,7,8-HxCDF	4	4	9.3-120	44.3	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	28-170	89.5	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	32-460	163	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
1,2,3,6,7,8-HxCDF	4	4	3.7-73	26.7	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	15-110	64.7	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	25-140	73.4	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
1,2,3,7,8,9-HxCDF	4	3	ND(2)-25	9.38	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	2	ND-4.4	1.58	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	2	ND-14	5.68	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
2,3,4,6,7,8-HxCDF	4	4	1.8-78	26.2	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	32-130	77.7	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	36-110	70.8	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments*
HxCDFs	1	1	2.0	2.0	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5cm, A,D
	1	1	2.0	2.0	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6cm, A,D
	1	0	ND(0.4)	NA	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9cm, A,D
	4	1	ND-12	3.0	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	17	ND-6,500	1,339	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	10	ND-377	133	NR	NY/MASS	NR	NR	10	A
	3	3	92-250	187	NR	Stockholm Sweden	Various	NR	12	A
	2	2	78-150	114	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	59-150	104	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	4	23-283	148	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E
	1	1	166	166	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	131	131	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
	5	5	930-8,600	4,106	NR	Hamburg Germany	Urban	NR	15	
Heptachlorodibenzofurans (MW=409.31)										
1,2,3,4,6,7,8-HpCDF	8	8	59-2180	558	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	12	12	130-1030	584	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	10	10	21-8400	1764	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments*
1,2,3,4,7,8,9-HpCDF	4	3	ND-42	14.2	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	4.3-91	33.2	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	4	ND-260	78.3	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
HpCDFs	4	3	ND-30	16	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	20	ND-53,000	11,715	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	10	ND-2,436	1,039	NR	NY/MASS	NR	NR	10	A
	3	3	190-1,500	997	NR	Stockholm Sweden	Various	NR	12	A
	2	2	79-180	130	Dry	Baltic Sea	Reference Site	NR	13	A
	4	4	11-410	178	Dry	Iggesund Sweden	Industrial	NR	13	A/papermill
	4	4	20-158	100	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E
	1	1	43	43	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	192	192	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
	5	5	560-4,300	2,358	NR	Hamburg Germany	Urban	NR	15	
Octachlorodibenzofurans (MW=444.76)										
1,2,3,4,6,7,8,9-OCDF	18	3	ND-160	14	Dry	South Central Finland	Various	88/89	1	A,B
	1	1	4	4	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	0-0.5cm, A,D
	1	1	3.2	3.2	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	5-6cm, A,D

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Weight basis	Location	Location description	Sample year	Ref. no.	Comments[a]
1,2,3,4,6,7,8,9-OCDF	1	1	1.1	1.1	Dry	Siskiwit Lake, Isle Royale, Lake Michigan	Pristine	NR	3	8-9cm, A,D
(continued)	4	1	ND-23	5.8	NR	Central Minnesota	Rural	NR	5	A/4 sites
	25	21	ND-400,000	34,912	NR	Ontario Canada	Industrial	88	8	A/25 sites
	12	11	ND-1,010	460	NR	NY/MASS	NR	NR	10	A
	3	1	ND-39	14	NR	Stockholm Sweden	Various	NR	12	A
	2	1	ND-3.8	1.9	Dry	Baltic Sea	Reference Site	NR	13	A
	4	2	ND-15	5	Dry	Iggesund Sweden	Industrial	NR	13	A/Papermill
	4	4	150-4250	1212	NR	Dala River, Sweden	Industrial	88	17	0-1 cm
	6	6	170-1310	602	NR	Lake Vattern, Sweden	Industrial	88	17	0-1 cm
	5	5	230-79,250	19,356	NR	Lake Vanern, Sweden	Industrial	88	17	0-1 cm
	4	4	58-151	96	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	0-2cm, E
	1	1	43	43	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	4-6cm, E
	1	1	192	192	Dry	Fjord between Sweden, Norway and Denmark	Industrial	87	14	9-13cm, E
	5	5	660-5,200	2,712	NR	Hamburg Germany	Urban	NR	15	

[a]Key:

A LOD (Ref. 1) = 20 to 50 ppt, LOD (Ref. 2) = 32 ppt, LOD (Ref. 3) = 0.4 ppt, LOD (Ref. 4) = 0.7 to 12.0 ppt, LOD (Ref. 5) = 0.61 to 4.1 ppt, LOD (Ref. 8) = 10 to 700 ppt, LOD (Ref. 10) = 3 ppt, LOD (ref. 12) = 1 to 20 ppt, LOD (Ref. 13) = 1 to 6.6 ppt.

B Dry surface sediments from 18 lakes.

C Industry produced 2,4,5 trichlorophenate (2,4,5T precursor).

D No anthropogenic inputs into drainage basin -- only atmospheric sources into lake.

E Mg-production facility.

Table B-6. Environmental Levels of Dibenzofurans in Sediment (ppt) (continued)

Notes

NR = Not Reported
NA = Not Applicable
ND = Not Detected
ppt = Parts per trillion

Sources:

1. Koistinen et al. (1990)
2. Bopp et al. (1991)
3. Czuczwa et al. (1984)
4. Norwood et al. (1989)
5. Reed et al. (1990)
6. Sonzongi et al. (1991)
7. Oliver and Nilmi (1988)
8. McKee et al. (1990)
9. Huckins et al. (1988)
10. Petty et al. (1982)
11. Sherman et al. (1990)
12. Rappe and Kjeller (1987)
13. Rappe et al. (1989a)
14. Oehme et al. (1989)
15. Gotz and Schumacher (1990)
16. Smith et al. (1990)
17. Kjeller et al. (1990)

Table B-7. Environmental Levels of PCBs in Sediment (ppt)

IUPAC number	Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments[a]
Tetrachloro-PCB (MW=291.99)											
77	3,3',4,4'-TCB	18	13	ND-550	138	Dry	South Central Finland	Various	88/89	1	A,B
		8	8	500-360,000	64,250	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		5	5	5,000-27.5M	9.47M	NR	Waukegan, Illinois	Urban	78	9	5 sites
		NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A
81	3,4,4',5-TCB	8	3	ND-90,000	26,880	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A
Pentachloro-PCB (MW=326.44)											
126	3,3',4,4',5-PeCB	18	1	ND-110	6.1	Dry	South Central Finland	Various	88/89	1	A,B
		8	2	ND-10,000	2,380	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A
105	2,3,3',4,4'-PeCB	10	10	52-120	96.4	Dry	South Central Finland	Various	88/89	1	A,B,C
		8	8	6,000-490,000	85,120	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		38	NR	NR	10,000	Dry	Lake Ontario	Various	81	7	Bottom Sediment
		5	5	102,000-131M	35.14M	NR	Waukegan, Illinois	Urban	78	9	5 Locations
		NR	NR	NR	5,800	Dry	Green Bay, Lake Michigan	Various	NR	16	A

Table B-7. Environmental Levels of PCBs in Sediment (ppt) (continued)

IUPAC number	Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments[a]
114	2,3,4,4',5-PeCB	8	1	ND-110,000	13,750	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		NR	NR	NR	1,000	Dry	Green Bay, Lake Michigan	Various	NR	16	A
118	2,3',4,4',5-PeCB	8	8	86,000-1.48M	351,620	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		38	NR	NR	15,000	Dry	Lake Ontario	Various	81	7	Bottom Sediment
		NR	NR	NR	11,000	Dry	Green Bay, Lake Michigan	Various	NR	16	A
		2	0	0.01	0.01	Dry	Alicante, Spain	Coastal	89/90	17	
Hexachloro-PCB (MW=360.88)											
156	2,3,3',4,4',5-HxCB	38	NR	NR	2,100	Dry	Lake Ontario	Various	81	7	Bottom Sediment
		NR	NR	NR	1,700	Dry	Green Bay, Lake Michigan	Various	NR	16	A
167	2,3',4,4',5,5'-HxCB	8	2	ND-80,000	15,500	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A
169	3,3',4,4',5,5'-HxCB	18	0	ND(20-50)	NA	Dry	South Central Finland	Various	88/89	1	A,B
		8	3	ND-19,000	4,800	Dry	Eastern Wisconsin	Industrial	88/89	6	A,D
		NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A
Heptachloro-PCB (MW=396.33)											
189	2,3,3',4,4',5,5'HpCB	NR	NR	NR	ND(500)	Dry	Green Bay, Lake Michigan	Various	NR	16	A

Table B-7. Environmental Levels of PCBs in Sediment (ppt) (continued)

[a]Key: A LOD (Ref. 1)=20 to 50 ppt, LOD (Ref. 6)=1,000 ppt, LOD (Ref. 16)=500 ppt.
B Dry Surface Sediments from 18 lakes.
C All collected samples not analyzed.
D Superfund/Michigan "Area of Concern" Site.

NOTES:

NR = Not Reported
NA = Not Applicable
ND = Not Detected
ppt = Parts per trillion

Sources:

1. Koistinen, et al. (1990)
6. Sonzongi, et al. (1991)
7. Oliver and Nilmi (1988)
9. Huckins, et al. (1988)
16. Smith, et al. (1990)
17. Prats, et al. (1992)

Table B-8. Environmental Levels of Dioxins in Fish (ppt)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
Tetrachlorodibenzo-p-dioxins (MW=321.98)												
2,3,7,8-TCDD	Eel	Liver	6	6	1.2-9.1	3.32	NR	Various, Netherlands	NR	NR	1	one sample near dump site
	Eel	Fillet	5	5	2.4-3.3	3.04	Fat	Rhine River, Germany	NR	88	2	up & downstream Basal
	Trout	Fillet	1	1	1.4	1.4	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Grayling	Fillet	1	1	3.8	3.8	Fat	Neckar River, Germany	Urban	88	2	
	Barbel	Fillet	1	1	5.1	5.1	Fat	Neckar River, Germany	Urban	88	2	
	Carp	Fillet	1	1	2.5	2.5	Fat	Neckar River, Germany	Urban	88	2	
	Chub	Fillet	1	0	ND(2.3)	NA	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Eel	Fillet	5	5	0.9-1.5	1.3	Fat	Neckar River, Germany	Urban	87-88	2	
	Bream		14	14	1.4-94.4	18.0	Fresh	Hamburg, Germany	Urban	84	4	
	Perch		3	3	1.8-8.1	5.9	Fresh	Hamburg, Germany	Urban	84	4	
	Herring	Whole	1	0	ND(0.1)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.1)	NA	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.1)	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
	Salmon	Muscle	2	2	4.6-19.0	11.8	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	wild salmon
	Salmon	Muscle	2	2	0.2-0.3	0.25	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	hatched salmon
	Perch	NR	3	3	2.6-19	11.5	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	caught near pulp mill
	Artic Char	NR	5	5	6.5-25	14.3	Fresh	Lake Vattern, Sweden	NR	NR	5	
	Pike	Muscle	8	8	40-833	186	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	78	78	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Ch. Catfish	Fillets	8	8	28-695	157	NR	Various, Michigan	NR	78	7	

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Carp	Fillets	14	10	20-153	55	NR	Various, Michigan	NR	78	7	
	Y. Perch	Fillets	6	3	10-20	13	NR	Various, Michigan	NR	78	7	
	Sm. M. Bass	Fillets	2	2	7-8	8	NR	Various, Michigan	NR	78	7	
	Sucker	Fillets	4	3	4-21	10	NR	Various, Michigan	NR	78	7	
	Lake Trout	Fillets	2	0	ND(5.0)	NA	NR	Various, Michigan	NR	78	7	
	Carp	Whole	3	0	ND(6.6)	NA	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	0	ND(6.6)	NA	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	2	2	3-28	16	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Blue Crab	Meat	2	2	106-116	111	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	4.7-6.3	5.5	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	83.9-734	409	Wet	Newark Bay, NJ	Urban	NR	10	
	Lake Trout	Whole	1	1	1.0	1.0	Wet	Lake Superior	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	8.6	8.6	Wet	Lake Huron	NR	84	11	mean 5 samples
	Lake Trout	Whole	3	3	3.5-5.8	4.4	Wet	Lake Michigan	NR	84	11	range 3 sample sites
	Walleye	Whole	1	1	1.8	1.8	Wet	Lake Erie	NR	84	11	mean 5 samples
	Walleye	Whole	1	1	6.6	6.6	Wet	Lake St. Clair	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	48.9	48.9	Wet	Lake Ontario	NR	84	11	mean 5 samples
	Lake Trout	Whole	10	10	3.0-8.7	4.2	Wet	Lake Michigan	NR	84	11	
	Br. Trout	Whole	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	5	5	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	14	14	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Rb. Trout	Fillets	1	1	5	5	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	18	18	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	20	20	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Cod	Fillets	4	0	ND(1.0)	NA	Fresh	Various, Sweden	Industrial	88	17	
	Haddock	Fillets	1	0	ND(0.2)	NA	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	P. Flounder	Fillets	1	0	ND(0.2)	NA	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Plaice	Fillets	1	0	ND(0.5)	NA	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Flounder	Fillets	1	0	ND(0.5)	NA	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Eel	Fillets	4	1	ND-1.4	0.35	Fresh	Various, Sweden	Industrial	87-88	17	
	Mussel	Muscle	3	0	ND(0.5)	NA	Fresh	Grenlandsfjord,Sweden	Industrial	87	17	
	Shrimp	Muscle	2	0	ND(2.0)	NA	Fresh	Grenlandsfjord,Sweden	Industrial	88	17	
	Cod	Fillets	6	NR	ND-3.8	NR	Fresh	Frierfjord, Sweden	Industrial	87	17	only conc. range given
	Various[c]	Mixed[d]	314	220	NR	6.84	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
	Sucker	Whole	15	6	ND- 0.85	0.45	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.74-1.39)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(0.96-1.49)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.17)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDD (contiued)	Sm Bass	Fillet	2	0	ND(0.99-1.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.00)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	2	ND- 0.46	0.48	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(1.15-2.35)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.27)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.34-0.75)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	2	1.87- 2.26	2.06	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(0.58)	NA	Wet	Various, US	Background	86-89	20	Samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	Samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(0.99)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	0.31	0.31	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.30)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.10-1.00)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.10-0.11)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.16)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Sea Catfish	Fillet	1	0	ND(1.00)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(1.00)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(1.02)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(1.04-1.11)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(1.01)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	1	ND- 1.20	1.02	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	1	0.75	0.75	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	0.75	0.75	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(0.99)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
TCDDs	Bream	NR	13	13	2.5-102	17.6	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	2	2	9.0-10.5	9.8	Fresh	Hamburg, Germany	Urban	84	4	
	Carp	Whole	3	1	ND-3.9	1.3	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	0	ND(6.6)	NA	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station
	Blue Crab	Meat	2	2	118-150	134	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	6.6-8.3	7.4	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	85.4-734	410	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	11	11	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
TCDDs (continued)	Br. Trout	Fillets	1	1	9	9	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	29	29	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	11	11	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	32	32	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	12	12	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	22	22	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	9	9	NR	Lake Ontario	NR	NR	12	composite 3 samples
Pentachlorodibenzo-p-dioxins (MW=356.42)												
1,2,3,7,8-PeCDD	Carp	Whole	2	2	2-11	6	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	8	8	70-250	129	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	39	39	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	1	0.6	0.6	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	2	1.1-2.8	1.95	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Sucker	Whole	15	2	ND- 0.54	0.72	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.75-2.18)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(2.74-2.99)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(0.92-0.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(0.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	Carp	Whole	5	1	ND-0.38	0.80	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(1.94-5.33)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.97)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.48-0.70)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(1.11-1.50)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.75)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(1.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	0.57	0.57	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(1.40)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.37-0.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.19-0.49)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(0.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(0.97)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	Summer Flounder	Whole	1	0	ND(1.21)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(0.92-0.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(0.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(1.20-1.24)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(1.61)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(1.01)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(0.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Herring	Whole	2	2	2.0-4.7	3.35	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
PeCDDs	Various[c]	Mixed[d]	34	34	0.15-2.67	0.77	Wet	Various, US	Background[e]	86-89	20	samples composite 3-5 fish
	Bream		13	13	3.2-27.8	12.1	Fresh	Hamburg, Germany	Urban	84	4	
	Perch		2	2	9.8-29.8	19.8	Fresh	Hamburg, Germany	Urban	84	4	
	Carp	Whole	3	3	3.5-4.5	3.9	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	0	ND(6.6)	NA	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station
	Blue Crab	Meat	2	2	17.2-18.0	17.6	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	10.0-11.0	10.5	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	5.2-10.6	7.9	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
PeCDDs (continued)	Rb. Trout	Whole	1	1	31	31	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	15	15	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	39	39	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	9	9	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	5	5	NR	Lake Ontario	NR	NR	12	composite 3 samples
Hexachlorodibenzo-p-dioxins (MW=390.87)												
1,2,3,4,7,8-HxCDD	Carp	Whole	2	2	3-5	4	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	8	8	6.7-22	12.8	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	11	11	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	2	0.2-0.3	0.25	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.2)	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
	Sucker	Whole	15	2	ND- 0.24	0.81	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.90-2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(2.47-2.87)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.25)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
	Carp	Whole	5	1	ND- 0.70	1.08	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
1,2,3,4,7,8-HxCDD (continued)	not available	Whole	2	0	ND(1.50-3.31)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.65-0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.89-1.04)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(1.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(2.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(2.56)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(1.13)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.60-2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.22-1.04)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.22)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,8-HxCDD (continued)	Summer Flounder	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(2.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(2.47)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	100	NR	1.67	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
1,2,3,6,7,8-HxCDD	Pike	Muscle	8	8	30-100	50.5	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	22	22	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	1	ND-2.4	1.25	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	2	2.2-8.1	5.15	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
	Sucker	Whole	15	4	ND- 0.46	0.97	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.90-2.40)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(2.87-3.71)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(3.49)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD (continued)	Sm Bass	Fillet	2	0	ND(1.84-1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	3	ND- 3.57	1.63	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(2.25-5.00)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.65-0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(1.74-1.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(1.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(1.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	1.36	1.36	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(1.13)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.60-1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.87-1.04)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.22)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD (continued)	Sea Catfish	Fillet	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	1	0.67	0.67	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(1.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	1	ND- 0.40	0.67	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(1.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	0.68	0.68	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(1.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	217	NR	4.29	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
1,2,3,7,8,9-HxCDD	Pike	Muscle	8	0	ND(3-11)	NA	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	0	ND(6)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.2)	NA	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.2)	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
	Sucker	Whole	15	0	ND(0.60-3.37)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.90-2.40)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8,9-HxCDD (continued)	Rock Bass	Whole	2	0	ND(2.47-2.87)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.25)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	0	ND(1.15-2,69)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(1.50-2.48)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.65-0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.89-1.04)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(1.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(1.37)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(1.13)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.60-1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8,9-HxCDD (continued)	Chain Pickerel	Fillet	3	0	ND(0.22-1.04)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.22)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	1	0.34	0.34	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(1.37-1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(1.38)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	119	NR	1.15	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
HxCDDs	Bream		13	13	4.3-46.4	17.8	Fresh	Hamburg, Germany	Urban	84	4	
	Perch		2	2	18.6-21.5	20.0	Fresh	Hamburg, Germany	Urban	84	4	
	Carp	Whole	3	3	2.3-11	6.9	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	1	ND-3.0	1.0	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
HxCDDs (continued)	Blue Crab	Meat	2	2	0.3-1.5	0.9	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	3.0-3.4	3.2	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	0.6-0.7	0.65	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	20	20	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	25	25	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	67	67	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	37	37	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	114	114	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	27	27	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	16	16	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	22	22	NR	Lake Ontario	NR	NR	12	composite 3 samples
Heptachlorodibenzo-p-dioxins (MW = 425.31)												
1,2,3,4,6,7,8-HpCDD	Carp	Whole	2	2	3-4	3.5	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	1	ND-0.6	0.35	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	0	ND(0.2)	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish
	Sucker	Whole	15	8	ND- 8.16	2.59	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	1	ND- 0.75	1.54	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(12.94-19.27)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
	Rock Bass	Fillet	1	0	ND(10.70)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
1,2,3,4,6,7,8-HpCDD (continued)	Sm Bass	Fillet	2	1	ND- 0.23	0.11	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.26)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	3	ND- 7.14	7.18	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	1	0	ND(6.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(4.91)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(1.31-4.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	2	1.67- 2.21	1.94	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	1	1.80	1.80	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(3.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(4.43)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	3.23	3.23	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(7.36)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	2	0	ND(0.75-0.86)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(3.08-5.09)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(2.29)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDD (continued)	Sea Catfish	Fillet	1	1	0.51	0.51	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	1	0.74	0.74	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	1	3.06	3.06	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	2	0.77- 0.79	0.78	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	1	2.18	2.18	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	2	0.61- 0.80	0.71	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(4.10)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	0.89	0.89	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	1	0.49	0.49	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	279	NR	10.5	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
HpCDDs	Bream		13	13	1.5-14.4	6.7	Fresh	Hamburg, Germany	Urban	84	4	
	Perch		2	2	3.5-7.1	5.3	Fresh	Hamburg, Germany	Urban	84	4	
	Carp	Whole	3	3	15-22	19.3	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	2	ND-11	7.0	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station
	Blue Crab	Meat	2	0	ND(1.1)	NA	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	1	ND-8.5	4.25	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	4.0-11.4	7.7	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	7	7	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
HpCDDs (continued)	Br. Trout	Fillets	1	1	9	9	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	12	12	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	16	16	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	30	30	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	50	50	NR	Lake Ontario	NR	NR	12	composite 3 samples
Octachlorodibenzo-p-dioxin (MW = 460.76)												
1,2,3,4,6,7,8,9-OCDD	Eel	Fillet	5	5	28-60	44.4	Fat	Rhine River, Germany	NR	88	2	up & downstream Basal
	Trout	Fillet	1	0	ND(5.0)	NA	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Grayling	Fillet	1	1	47	47	Fat	Neckar River, Germany	Urban	88	2	
	Barbel	Fillet	1	1	9.0	9	Fat	Neckar River, Germany	Urban	88	2	
	Carp	Fillet	1	1	23	23	Fat	Neckar River, Germany	Urban	88	2	
	Chub	Fillet	1	1	15	15	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Eel	Fillet	5	5	25-40	30	Fat	Neckar River, Germany	Urban	87-88	2	
	Bream		14	14	1.4-5.1	2.5	Fresh	Hamburg, Germany	Urban	84	4	
	Perch		3	3	2.3-10.5	5.2	Fresh	Hamburg, Germany	Urban	84	4	
	Herring	Whole	1	1	1.1	1.1	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 5-10 fish
	Herring	Whole	2	1	ND-0.7	0.4	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 5-10 fish
	Herring	Whole	2	1	ND-0.3	0.2	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 5-10 fish

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	Salmon	Muscle	2	1	ND-1.5	0.75	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	wild salmon
	Salmon	Muscle	2	2	0.8-1.9	1.35	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	hatched salmon
	Perch	NR	3	3	0.6-0.8	0.73	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	caught near pulp mill
	Pike	Muscle	8	8	10-17	14.75	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	22	22	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Carp	Whole	3	3	56-62	59	NR	Mississippi River, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	3	3	35-43	39	NR	Lake Orono, MN	Industrial	NR	8	Elk River power station
	Carp	Whole	2	2	3-5	4	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Blue Crab	Meat	2	2	34.3-78.8	56.6	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	6.3-10.9	8.6	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	5.1-49.5	27.3	Wet	Newark Bay, NJ	Urban	NR	10	
	Lake Trout	Whole	1	1	1.0	1.0	Wet	Lake Superior	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	0.7	0.7	Wet	Lake Huron	NR	84	11	mean 5 samples
	Lake Trout	Whole	3	3	1.1-2.5	1.8	Wet	Lake Michigan	NR	84	11	range 3 sample sites
	Walleye	Whole	1	1	2.8	2.8	Wet	Lake Erie	NR	84	11	mean 5 samples
	Walleye	Whole	1	1	1.8	1.8	Wet	Lake St. Clair	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	1.2	1.2	Wet	Lake Ontario	NR	84	11	mean 5 samples
	Lake Trout	Whole	10	10	0.8-3.7	1.6	Wet	Lake Michigan	NR	84	11	
	Br. Trout	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	11	11	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8-OCDD (continued)	Rb. Trout	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	89	89	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	28	28	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	160	160	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	280	280	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Cod	Fillets	4	3	ND-11	4.95	Fresh	Various, Sweden	Industrial	88	17	
	Haddock	Fillets	1	0	ND(3.6)	NA	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	P. Flounder	Fillets	1	1	3.4	3.4	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Plaice	Fillets	1	1	424	424	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Flounder	Fillets	1	1	2.4	2.4	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Eel	Fillets	4	3	ND-770	204	Fresh	Various, Sweden	Industrial	87-88	17	
	Mussel	Muscle	3	3	12-140	62.0	Fresh	Grenlandsfjord,Sweden	Industrial	87	17	
	Shrimp	Muscle	2	1	ND-18	9.0	Fresh	Grenlandsfjord,Sweden	Industrial	88	17	
	Cod	Fillets	6	NR	0.63-2.2	NR	Fresh	Frierfjord, Sweden	Industrial	87	17	only conc. range given

Table B-8. Environmental Levels of Dioxins in Fish (ppt) (continued)

Footnote References

[a] Ch. = Channel; Y. = Yellow; Sm. M. = Small Mouth; Str. = Striped; Br. = Brown; Rb. = Rainbow; P. = Pole.
[b] Various, Netherlands = samples taken from six locations around Ijsselmeer Lake; Various, Michigan = samples taken from Tittabawassee River, Grand River, Saginaw River, Saginaw Bay, and Lake Michigan; Various, Sweden = samples taken from Grenlandsfjord and Frierfjord; Various US = samples taken from 314 sites across the US, including industrial and background sites.
[c] Species were taken from both bottom feeders and open water feeders, and then composited.
[d] Whole fish samples and fillet samples were combined during analysis.

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = not applicable;
ND = non-detected (limit of detection);
NR = not reported;
Descriptions provided were those given by reference or surmised from study description when not given;
One half the detection limit was used in calculating means. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).

Sources:
1. Van den Berg, et al. (1987)
2. Frommberger (1991)
4. Gotz, et al. (1990)
5. Rappe, et al. (1989)
7. Harless and Lewis (1982)
8. Reed, et al. (1990)
10. Rappe, et al. (1991)
11. Vault, et al. (1989)
12. Niimi and Oliver (1989a)
17. Oehme, et al. (1989)
18. Stalling, et al. (1983)
19. Kjeller, et al. (1990)
20. USEPA (1992)

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
Tetrachlorodibenzofurans (MW=305.98)												
2,3,7,8-TCDF	Eel	Liver	6	0	ND	NA	NR	Various, Netherlands	NR	NR	1	one sample near dump site
	Eel	Fillets	5	5	2.1-12	6.98	Fat	Rhine River, Germany	NR	88	2	up & downstream Basal
	Br. Trout	Fillets	1	1	45	45	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Grayling	Fillets	1	1	108	108	Fat	Neckar River, Germany	Urban	88	2	
	Barbel	Fillets	1	1	57	57	Fat	Neckar River, Germany	Urban	88	2	
	Carp	Fillets	1	1	58	58	Fat	Neckar River, Germany	Urban	88	2	
	Chub	Fillets	1	1	128	128	Fat	Neckar River, Germany	Urban	88	2	composite sample
	Eel	Fillets	5	5	0.9-2.0	1.35	Fat	Neckar River, Germany	Urban	87-88	2	
	Herring	Adipose	2	2	3-4	3.5	Fat	South Baltic Sea	NR	NR	3	
	Herring	Whole	1	1	1.7	1.7	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	5.3-5.5	5.4	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	3.0-6.2	4.6	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Salmon	Muscle	2	2	28-35	31.5	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	wild salmon
	Salmon	Muscle	2	2	7.8-9.0	8.4	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	hatched salmon
	Perch	NR	3	3	2.1-8.7	5.4	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	caught near pulp mill
	Artic Char	NR	5	5	21-75	55	Fresh	Lake Vattern, Sweden	NR	NR	5	
	Pike	Muscle	8	8	330-3000	774	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	430	430	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Carp	Whole	2	2	11	NA	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Carp	Whole	3	3	1.8-3.0	2.6	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Carp	Whole	3	3	1.0-1.3	1.1	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Carp	Fillets	1	1	49	49	NR	NR	NR	78	9	contamimated site
	Catfish	Fillets	1	1	6	6	NR	Saginaw River	NR	84	9	contaminated site
	Smk. Chub	Fillets	1	1	3	3	NR	NR	NR	85	9	contaminated site
	Str. Bass	Fillets	5	5	7-93	28.0	NR	Hudson River	NR	85	9	contaminated site
	Lg. M. Bass	Fillets	1	1	10	10	NR	Hudson River	NR	85	9	contaminated site
	Lake Trout	Fillets	3	3	11-56	31.7	NR	Lake Superior	NR	85	9	contaminted site
	Blue Crab	Meat	2	2	11.0-15.5	13.2	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	3.5-4.1	3.8	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	51.9-85.5	68.7	Wet	Newark Bay, NJ	Urban	NR	10	
	Lake Trout	Whole	1	1	14.8	14.8	Wet	Lake Superior	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	22.8	22.8	Wet	Lake Huron	NR	84	11	mean 5 samples
	Lake Trout	Whole	3	3	34.8-42.3	39.5	Wet	Lake Michigan	NR	84	11	range 3 sample sites
	Walleye	Whole	1	1	11.3	11.3	Wet	Lake Erie	NR	84	11	mean 5 samples
	Walleye	Whole	1	1	24.8	24.8	Wet	Lake St. Clair	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	18.5	18.5	Wet	Lake Ontario	NR	84	11	mean 5 samples
	Lake Trout	Whole	10	10	27.0-56.0	38.4	Wet	Lake Michigan	NR	84	11	
	Br. Trout	Whole	1	1	11	11	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	19	19	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Lake Trout	Whole	1	1	15	15	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	20	20	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Cod	Fillets	4	4	0.2-1.4	0.62	Fresh	Various, Sweden	Industrial	88	17	
	Haddock	Fillets	1	1	0.75	0.75	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	P. Flounder	Fillets	1	1	0.28	0.28	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Plaice	Fillets	1	1	1.4	1.4	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Flounder	Fillets	1	1	1.2	1.2	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Eel	Fillets	4	3	ND-68	17.1	Fresh	Various, Sweden	Industrial	88	17	
	Mussel	Muscle	3	3	16.1-61	32.4	Fresh	Grenlandsfjord,Sweden	Industrial	87	17	
	Shrimp	Muscle	2	2	6.1-37	21.6	Fresh	Grenlandsfjord,Sweden	Industrial	88	17	
	Cod	Fillets	6	NR	0.49-14.3	NR	Fresh	Frierfjord, Sweden	Industrial	87	17	only conc. range given
	Various[c]	Mixed[d]	314	279	NR	13.6	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
	Sucker	Whole	15	12	ND- 6.21	1.96	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.23-0.59)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	1	ND- 0.86	1.24	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	2	0.19- 0.30	0.25	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(0.49)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Carp	Whole	5	4	ND- 1.36	0.96	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 0.29	0.37	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	2	0.75- 0.90	0.83	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(0.48)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	1	2.30	2.30	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	1.77	1.77	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.41)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	1	ND- 0.86	0.41	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.20- 0.24)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(0.49)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(0.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(0.71)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Dolly Varden	Whole	2	2	0.37	0.37	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	1	0.86	0.86	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	2	13.30-13.73	13.52	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	1	1.93	1.93	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	1.14	1.14	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(0.57)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
TCDFs	Bream	NR	13	13	7.8-86.5	44.3	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	2	2	10.7-41.1	25.9	Fresh	Hamburg, Germany	Urban	84	4	
	Y. Perch	Whole	1	1	1060	1060	NR	Housatonic River, MA	NR	NR	6	
	Carp	Whole	3	3	2.4-4.0	3.1	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station
	Carp	Whole	3	3	1.0-1.3	1.2	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Blue Crab	Meat	2	2	133-164	149	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	23.0-31.2	27.1	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	77.2-108	92.4	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	11	11	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	19	19	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	18	18	NR	Lake Ontario	NR	NR	12	composite 3 samples

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
TCDFs (continued)	Lake Trout	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	20	20	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	1	6	6	NR	Lake Ontario	NR	NR	12	composite 3 samples
TCDFs other than 2,3,7,8-TCDF	Eel	Fillets	5	5	4.6-13	8.8	Fat	Rhine River, Germany	NR	88	2	up & downstream Basal
	Grayling	Fillets	1	1	142	142	Fat	Neckar River, Germany	Urban	88	2	
	Barbel	Fillets	1	1	77	77	Fat	Neckar River, Germany	Urban	88	2	
	Carp	Fillets	1	1	14	14	Fat	Neckar River, Germany	Urban	88	2	
	Chub	Fillets	1	1	17	17	Fat	Neckar River, Germany	Urban	88	2	sample composite 5 chubs
	Eel	Fillets	1	1	1.5	1.5	Fat	Neckar River, Germany	Urban	88	2	sample composite 2 eels
Pentachlorodibenzofurans (MW=340.42)												
1,2,3,7,8-PeCDF	Carp	Whole	2	2	1-5	3	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	8	8	43-140	73.2	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	39	39	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	1	0.4	0.4	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	1.4-2.5	1.95	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.8-0.9	0.85	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Various[c]	Mixed[d]	314	151	NR	1.71	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
	Sucker	Whole	15	1	ND- 0.62	0.33	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.33-0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8-PeCDF (continued)	Rock Bass	Whole	2	0	ND(0.76-0.82)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.59)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	1	ND- 0.33	0.16	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	0	ND(0.56-0.80)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 0.92	0.69	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.36)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.20-0.35)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	1	ND- 0.47	0.51	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(0.90)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.25)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(0.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.20-0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8-PeCDF (continued	Chain Pickerel	Fillet	3	0	ND(0.19-0.28)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(0.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(0.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	2	1.74- 1.90	1.82	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	1	1.06	1.06	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	0.73	0.73	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	34	34	0.1-1.90	0.43	Wet	Various, US	Background[b]	86-89	20	samples composite 3-5 fish
2,3,4,7,8-PeCDF	Carp	Whole	2	2	4-11	7.5	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	8	8	120-290	189	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	110	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	1	3.0	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	6.8-19.0	12.9	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	8.8-8.9	8.85	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	Sucker	Whole	15	6	ND- 1.36	0.46	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.33-0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(0.76-0.82)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.59)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	2	ND- 0.34	0.35	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 1.33	0.82	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.36)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.20-0.35)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	2	0.70	0.70	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(0.90)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.25)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(0.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(0.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	Walleye	Fillet	3	0	ND(0.20-0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.19-0.28)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	2	0.64- 0.70	0.67	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	1	0.93	0.93	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	1	1.39	1.39	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(0.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	201	NR	3.06	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
PeCDFs	Bream	NR	13	13	13.9-114	65.4	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	2	2	62.3-153	108	Fresh	Hamburg, Germany	Urban	84	4	
	Y. Perch	Whole	1	1	640	640	NR	Housatonic River, MA	NR	NR	6	
	Carp	Whole	3	3	15-45	26.3	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
PeCDFs (continued)	Carp	Whole	3	2	ND-13	9.0	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Blue Crab	Meat	2	2	89.7-94.1	91.9	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	29.8-37.3	33.6	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	34.3-82.6	58.4	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	1	3	3	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	7	7	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	39	39	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	1	13	13	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
PeCDFs other than 1,2,3,7,8-PeCDF and 2,3,4,7,8-PeCDF	Grayling	Fillets	1	1	22	22	Fat	Neckar River, Germany	Urban	88	2	
	Barbel	Fillets	1	1	21	21	Fat	Neckar River, Germany	Urban	88	2	
	Carp	Fillets	1	1	17	17	Fat	Neckar River, Germany	Urban	88	2	
Hexachlorodibenzofurans (MW=374.87)												
1,2,3,4,7,8-HxCDF	Carp	Whole	2	2	2-5	3.5	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	8	8	10-33	14.4	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	1	11	11	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	1	0.2	0.2	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	Herring	Whole	2	2	0.4-0.7	0.55	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.3	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Sucker	Whole	15	0	ND(0.33-2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.41-2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(1.13-1.30)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(2.83-2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	1	ND- 0.40	0.98	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 1.24	0.81	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.23-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.45-0.58)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(2.82)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	Golden Redhorse	Whole	1	1	1.18	1.18	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.21-2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.20-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(2.83)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(2.83)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(2.83-2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(2.83)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	132	NR	2.35	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
1,2,3,6,7,8-HxCDF	Pike	Muscle	8	8	5.6-22	11.9	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,6,7,8-HxCDF (continued)	Pike	Muscle	1	1	5.6	5.6	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	1	0.1	0.1	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.4-0.8	0.6	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.2	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Sucker	Whole	15	0	ND(0.26-2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.41-2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(1.13-1.30)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(2.84-2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	0	ND(0.52-2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 1.35	0.87	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.23-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.45-0.58)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,6,7,8-HxCDF (continued)	Gray Redhorse	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(2.83)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.21-2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.20-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(2.84)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8,9-HxCDF (continued)	Crayfish	Whole	1	0	ND(2.85)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	66	NR	1.74	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
	Pike	Muscle	8	0	ND(3-6)	NA	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	0	ND(6)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Sucker	Whole	15	0	ND(0.26-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.41-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(1.13-1.30)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(2.77-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	0	ND(0.52-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(0.77-0.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.23-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.39-0.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(1.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,7,8,9-HxCDF (continued)	Gray Redhorse	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	lack Redhorse	Whole	1	0	ND(2.76)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.21-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.20-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(2.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(2.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(2.77-2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(2.77)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(2.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,4,6,7,8-HxCDF	Various[c]	Mixed[d]	314	3	NR	1.22	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
	Pike	Muscle	8	7	ND(3-17)	7.96	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	0	ND(6)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.4-0.8	0.6	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.3	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Sucker	Whole	15	0	ND(0.26-1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	4	0	ND(0.41-1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(1.13-1.30)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(0.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	1	ND- 0.92	0.76	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(0.78-2.72)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Whole	1	0	ND(0.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.23-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.45-0.58)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,4,6,7,8-HxCDF (continued)	Brook Trout	Fillet	1	0	ND(1.46)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Gray Redhorse	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(1.95)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	1.25	1.25	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(0.52)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.21-1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.20-0.42)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.20)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(1.97)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(1.95-1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,4,6,7,8-HxCDF (continued)	White Catfish	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Crayfish	Whole	1	0	ND(1.96)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	100	NR	1.24	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
HxCDFs	Bream	NR	13	13	5.7-47.4	25.2	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	2	2	21.9-53.8	37.8	Fresh	Hamburg, Germany	Urban	84	4	
	Y. Perch	Whole	1	1	440	440	NR	Housatonic River, MA	NR	NR	6	
	Carp	Whole	3	2	ND-24	10.0	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station
	Carp	Whole	3	3	2.7-5.1	3.5	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Blue Crab	Meat	2	2	9.3-9.4	9.35	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	2	7.7-7.9	7.8	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	2.0-4.4	3.2	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	1	2	2	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	8	8	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	1	2	2	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	16	16	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
non-2,3,7,8-HxCDFs	Barbel	Fillets	1	1	2.1	2.1	Fat	Neckar River, Germany	Urban	88	2	

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
Heptachlorodibenzofurans (MW=409.31)												
1,2,3,4,6,7,8-HpCDF (continued)	Carp	Whole	2	2	3-4	3.5	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Pike	Muscle	16	1	ND(3-7)-17	3.41	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	2	0	ND(6-11)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	2	0.8-1.2	1.0	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	1	ND-0.9	0.5	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Sucker	Whole	15	3	ND- 1.88	0.96	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	2	0	ND(1.44-1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(6.61-8.89)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.40)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	5	3	ND- 1.31	0.71	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	1	ND- 1.13	2.21	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.77-0.80)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	1	ND- 0.48	0.56	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(4.13)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDF (continued)	Gray Redhorse	Whole	1	0	ND(2.75)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(2.25)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	1	1.25	1.25	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(3.11)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.71-1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.27-1.28)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.35)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	1	0.27	0.27	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(1.44-1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	1	0.23	0.23	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(1.78)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDF (continued)	Crayfish	Whole	1	0	ND(1.45)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Various[c]	Mixed[d]	314	170	NR	1.91	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
1,2,3,4,7,8,9-HpCDF	Pike	Muscle	8	0	ND(3-11)	NA	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	0	ND(6)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Sucker	Whole	15	0	ND(0.71-4.23)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Lm Bass	Fillet	2	0	ND(2.61-2.26)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Whole	2	0	ND(2.64-5.92)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rock Bass	Fillet	1	0	ND(1.40)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sm Bass	Fillet	2	0	ND(2.61-2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Redeye Bass	Fillet	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Carp	Whole	3	0	ND(2.61-2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	not available	Whole	2	0	ND(1.12-1.64)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brown Trout	Fillet	2	0	ND(0.77-0.80)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Rainbow Trout	Fillet	2	0	ND(0.63-0.91)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Brook Trout	Fillet	1	0	ND(4.13)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,8,9-HpCDF (continued)	Gray Redhorse	Whole	1	0	ND(2.75)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Redhorse	Whole	1	0	ND(3.82)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Golden Redhorse	Whole	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Longear Sunfish	Whole	1	0	ND(3.11)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Walleye	Fillet	3	0	ND(0.71-2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Chain Pickerel	Fillet	3	0	ND(0.27-1.28)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Black Crappie	Fillet	1	0	ND(0.23)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Sea Catfish	Fillet	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	North Hogsucker	Whole	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Summer Flounder	Whole	1	0	ND(2.61)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Dolly Varden	Whole	2	0	ND(2.61)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Composite Bottom	Whole	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Winter Flounder	Whole	2	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	Bluefish	Whole	1	0	ND(3.12)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
	White Catfish	Whole	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,7,8,9-HpCDF	Crayfish	Whole	1	0	ND(2.62)	NA	Wet	Various, US	Background	86-89	20	samples composite 3-5 fish
(continued)	Various[c]	Mixed[d]	314	13	NR	1.24	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
HpCDFs	Bream	NR	13	13	1.8-6.0	3.6	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	2	2	5.0-10.1	7.6	Fresh	Hamburg, Germany	Urban	84	4	
	Y. Perch	Whole	1	0	ND(5.0)	NA	NR	Housatonic River, MA	NR	NR	6	
	Carp	Whole	3	1	ND-14	4.7	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station
	Carp	Whole	3	0	ND(6.6)	NA	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Blue Crab	Meat	2	2	2.8-3.5	3.15	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	0	ND(0.9)	NA	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	2	1.3-2.4	1.8	Wet	Newark Bay, NJ	Urban	NR	10	
	Br. Trout	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Br. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	1	1	1	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	1	1	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
Octachlorodibenzofurans (MW=444.76)												
1,2,3,4,6,7,8,9-OCDF	Bream	NR	14	10	ND-3.1	1.2	Fresh	Hamburg, Germany	Urban	84	4	
	Perch	NR	3	3	1.1-8.3	3.7	Fresh	Hamburg, Germany	Urban	84	4	

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDF (continued)	Herring	Whole	1	0	ND(0.2)	NA	Fresh	Atlantic Coast, Sweden	Pristine	NR	5	composite 2-5 fish
	Herring	Whole	2	1	ND-0.3	0.2	Fresh	Baltic Sea, Sweden	Urban	NR	5	composite 2-5 fish
	Herring	Whole	2	0	ND(0.2)	NA	Fresh	Gulf of Bothnia, Sweden	Industrial	NR	5	composite 2-5 fish
	Salmon	Muscle	2	0	ND(2.0)	NA	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	wild salmon
	Salmon	Muscle	2	0	ND(0.5)	NA	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	hatched salmon
	Perch	NR	3	1	ND-1.7	0.57	Fresh	Gulf of Bothnia, Sweden	NR	NR	5	caught near pulp mill
	Pike	Muscle	8	0	ND(3-11)	NA	Fat	Lake Vanern, Sweden	Industrial	88	19	samples composite 2-5 fish
	Pike	Muscle	1	0	ND(11)	NA	Fat	Hedesunda Bay, Sweden	Industrial	88	19	composite 5 fish
	Carp	Whole	2	2	4-8	6	NR	Lake Huron	NR	NR	18	samples composite 3-5 fish
	Y. Perch	Whole	1	0	ND(5.0)	NA	NR	Housatonic River, MA	NR	NR	6	
	Carp	Whole	3	0	ND(6.6)	NA	NR	Mississippi River, MN	Industrial	NR	8	Elk river power station
	Carp	Whole	3	3	ND(6.6)	NA	NR	Lake Orono, MN	Industrial	NR	8	Elk river power station
	Blue Crab	Meat	2	0	ND(8.3)	NA	Wet	Passaic River, NJ	Urban	NR	10	
	Lobster	Meat	2	0	ND(8.4)	NA	Wet	New York Bight	Dump Site	NR	10	former sewage sludge
	Str. Bass	Fillets	2	0	ND(3.1)	NA	Wet	Newark Bay, NJ	Urban	NR	10	
	Lake Trout	Whole	1	1	0.4	0.4	Wet	Lake Superior	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	0.1	0.1	Wet	Lake Huron	NR	84	11	mean 5 samples
	Lake Trout	Whole	3	3	0.3-1.0	0.85	Wet	Lake Michigan	NR	84	11	range 3 sample sites
	Walleye	Whole	1	1	0.9	0.9	Wet	Lake Erie	NR	84	11	mean 5 samples
	Walleye	Whole	1	1	0.4	0.4	Wet	Lake St. Clair	NR	84	11	mean 5 samples
	Lake Trout	Whole	1	1	0.4	0.4	Wet	Lake Ontario	NR	84	11	mean 5 samples

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Chemical	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDF (continued)	Br. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Rb. Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Whole	1	1	2	2	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Lake Trout	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Whole	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Coho Salmon	Fillets	1	0	ND(7)	NA	NR	Lake Ontario	NR	NR	12	composite 3 samples
	Cod	Fillets	4	4	3.4-9.6	6.3	Fresh	Various, Sweden	Industrial	88	17	
	Haddock	Fillets	1	1	4.3	4.3	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	P. Flounder	Fillets	1	1	4.7	4.7	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Plaice	Fillets	1	1	41	41	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Flounder	Fillets	1	1	5.6	5.6	Fresh	Various, Sweden	Industrial	88	17	composite 10 samples
	Eel	Fillets	4	4	31-581	205	Fresh	Various, Sweden	Industrial	88	17	
	Mussel	Muscle	3	3	13.4-933	339	Fresh	Grenlandsfjord,Sweden	Industrial	87	17	
	Shrimp	Muscle	2	2	2.3-41	21.6	Fresh	Grenlandsfjord,Sweden	Industrial	88	17	
	Cod	Fillets	6	NR	ND-21	NR	Fresh	Frierfjord, Sweden	Industrial	87	17	only conc. range given

Table B-9. Environmental Levels of Dibenzofurans in Fish (ppt) (continued)

Footnote References

[a] Br. = Brown; Smk. = Smoked; Str. = Striped; Lg. M. = Large Mouth; Rb. = Rainbow; P. = Pole; Y. = Yellow.

[b] Various, Netherlands = samples taken from six locations around IJsselmeer Lake; Various, Sweden = samples taken from Grenlandsfjord and Frierfjord; Various US = samples taken from 314 sites across the US, including industrial and background sites.

[c] Species were taken from both bottom feeders and open water feeders, and then composited.

[d] Whole fish samples and fillet samples were combined during analysis.

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = not applicable;
ND = non-detected (limit of detection);
NR = not reported;
Descriptions provided were those given by reference or surmised from study description when not given;
One half the detection limit was used in calculating means. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for non detects greater than the positive sample).

Sources:
1. Van den Berg, et al. (1987)
2. Frommberger (1991)
3. Rappe, et al. (1984)
4. Gotz, et al. (1990)
5. Rappe, et al. (1989)
8. Reed, et al. (1990)
9. Gardner and White (1990)
10. Rappe, et al. (1991)
11. Vault, et al. (1989)
12. Niimi and Oliver (1989a)
17. Oehme, et al. (1989)
18. Stalling, et al. (1983)
19. Kjeller, et al. (1990)
20. USEPA (1992)

Table B-10. Environmental Levels of PCBs in Fish (ppt)

Chemical (IUPAC number)	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
Tetrachloro-PCB (MW=291.99)												
3,3',4,4'-TCB (77)	Blk. Bullhead	Whole	1	1	89,000	89,000	NR	Waukegan Harbor, IL	NR	78	13	composite 6 samples
	Lg. M. Bass	Whole	1	1	86,000	86,000	NR	Waukegan Harbor, IL	NR	78	13	
	Blk. Crappie	Whole	1	1	43,000	43,000	NR	Waukegan Harbor, IL	NR	78	13	composite 3 samples
	Wh. Sucker	Whole	1	1	50,000	50,000	NR	Waukegan Harbor, IL	NR	78	13	composite 6 samples
	Coho Salmon	Whole	1	1	2,000	2,000	NR	Waukegan Harbor, IL	NR	78	13	
	Wh. Crappie	Whole	1	1	24,000	24,000	NR	Waukegan Harbor, IL	NR	78	13	
	Y. Perch	Whole	1	1	23,000	23,000	NR	Waukegan Harbor, IL	NR	78	13	composite 5 samples
	Br. Trout	Whole	1	1	5,000	5,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Br. Trout	Fillets	1	1	2,000	2,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Whole	1	1	18,000	18,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Fillets	1	1	8,000	8,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Rb. Trout	Whole	2	2	6000-11,000	8,500	NR	Lake Ontario	NR	NR	15	
	Rb. Trout	Fillets	2	1	ND-4,000	2,000	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Whole	2	2	8000-10,000	9,000	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Fillets	2	2	3,000-5,000	4,000	NR	Lake Ontario	NR	NR	15	
	Carp	Whole	1	0	ND(5,000)	NA	NR	Saginaw Bay	NR	NR	16	
3,4,4',5-TCB (81)	Br. Trout	Whole	1	1	24,000	24,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Br. Trout	Fillets	1	1	10,000	10,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Whole	1	1	90,000	90,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Fillets	1	1	38,000	38,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples

Table B-10. Environmental Levels of PCBs in Fish (ppt) (continued)

Chemical (IUPAC number)	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
3,4,4',5-TCB (continued)	Rb. Trout	Whole	2	2	13,000-30,000	21,500	NR	Lake Ontario	NR	NR	15	
	Rb. Trout	Fillets	2	1	ND-9,000	4,500	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Whole	2	2	2,000-26,000	14,000	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Fillets	2	2	8,000-14,000	11,000	NR	Lake Ontario	NR	NR	15	
	Carp	Whole	1	1	17,000	NA	NR	Saginaw Bay	NR	NR	16	
TCBs	Various[c]	Mixed[d]	362	263	NR	696,240	Wet	Various, US	Various	86-89	20	samples composite 3-5 fish
Pentachloro-PCB (MW=326.44)												
3,3',4,4',5-PeCB (126)	Carp	Whole	1	0	ND(5,000)	NA	NR	Saginaw Bay	NR	NR	16	
2,3,3',4,4'-PeCB (105)	Blk. Bullhead	Whole	1	1	352,000	352,000	NR	Waukegan Harbor, IL	NR	78	13	composite 6 samples
	Lg. M. Bass	Whole	1	1	290,000	290,000	NR	Waukegan Harbor, IL	NR	78	13	
	Blk. Crappie	Whole	1	1	114,000	114,000	NR	Waukegan Harbor, IL	NR	78	13	composite 3 samples
	Wh. Sucker	Whole	1	1	483,000	483,000	NR	Waukegan Harbor, IL	NR	78	13	composite 6 samples
	Coho Salmon	Whole	1	1	45,000	45,000	NR	Waukegan Harbor, IL	NR	78	13	
	Wh. Crappie	Whole	1	1	242,000	242,000	NR	Waukegan Harbor, IL	NR	78	13	
	Y. Perch	Whole	1	1	80,000	80,000	NR	Waukegan Harbor, IL	NR	78	13	composite 5 samples
	Small Smelt	Whole	1	1	15,000	15,000	Wet	Port Credit, Lake Ontario	NR	86	14	composite 48 samples
	Large Smelt	Whole	1	1	38,000	38,000	Wet	Vineland, Lake Ontario	NR	82	14	composite 20 samples
	Salmonids	Whole	1	1	110,000	110,000	Wet	Lake Ontario	NR	81-82	14	composite 60 samples
	Br. Trout	Whole	1	1	55,000	55,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Br. Trout	Fillets	1	1	24,000	24,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples

Table B-10. Environmental Levels of PCBs in Fish (ppt) (continued)

Chemical (IUPAC number)	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
2,3,3',4,4'-PeCB (continued)	Lake Trout	Whole	1	1	253,000	253,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Fillets	1	1	101,000	101,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Rb. Trout	Whole	2	2	34,000-138,000	86,000	NR	Lake Ontario	NR	NR	15	
	Rb. Trout	Fillets	2	2	6,000-50,000	28,000	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Whole	2	2	48,000-121,000	84,500	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Fillets	2	2	19,000-56,000	37,500	NR	Lake Ontario	NR	NR	15	
	Carp	Whole	1	1	427,000	427,000	NR	Saginaw Bay	NR	NR	16	
2,3,4,4',5-PeCB (114)	Carp	Whole	1	1	57,000	57,000	NR	Saginaw Bay	NR	NR	16	
2,3',4,4',5-PeCB (118)	Small Smelt	Whole	1	1	37,000	37,000	Wet	Port Credit, Lake Ontario	NR	86	14	composite 48 samples
	Large Smelt	Whole	1	1	87,000	87,000	Wet	Vineland, Lake Ontario	NR	82	14	composite 20 samples
	Salmonids	Whole	1	1	250,000	250,000	Wet	Lake Ontario	NR	81-82	14	composite 60 samples
	Br. Trout	Whole	1	1	133,000	133,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Br. Trout	Fillets	1	1	60,000	60,000	NR	Vineland, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Whole	1	1	634,000	634,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Lake Trout	Fillets	1	1	242,000	242,000	NR	Port Credit, Lake Ontario	NR	NR	15	composite 10 samples
	Rb. Trout	Whole	2	2	80,000-310,000	195,000	NR	Lake Ontario	NR	NR	15	
	Rb. Trout	Fillets	2	2	16,000-115,000	65,500	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Whole	2	2	100,000-271,000	185,500	NR	Lake Ontario	NR	NR	15	
	Coho Salmon	Fillets	2	2	39,000-136,000	87,500	NR	Lake Ontario	NR	NR	15	
	Carp	Whole	1	1	1.35×10^6	1.35×10^6	NR	Saginaw Bay	NR	NR	16	

Table B-10. Environmental Levels of PCBs in Fish (ppt) (continued)

Chemical (IUPAC number)	Fish species[a]	Tissue	Number samples	Number positive samples	Concentration range	Conc. mean	Wt. basis	Location[b]	Location description	Samp. year	Ref. no.	Comments
PeCBs	Various[c]	Mixed[d]	362	314	NR	564,700	Wet	Various, US	Various	86-89	20	composite 3-5 fish
Hexachloro-PCB (MW=360.88)												
3,3',4,4',5,5'-HxCB (169)	Carp	Whole	1	0	ND(5,000)	NA	NR	Saginaw Bay	NR	NR	16	
2,3,3',4,4',5-HxCB (156)	Small Smelt	Whole	1	1	2,700	2,700	Wet	Port Credit, Lake Ontario	NR	86	14	composite 48 samples
	Large Smelt	Whole	1	1	6,100	6,100	Wet	Vineland, Lake Ontario	NR	82	14	composite 20 samples
	Salmonids	Whole	1	1	34,000	34,000	Wet	Lake Ontario	NR	81-82	14	composite 60 samples
	Carp	Whole	1	1	79,000	79,000	NR	Saginaw Bay	NR	NR	16	
2,3,3',4,4',5'-HxCB (157)	Carp	Whole	1	1	76,000	76,000	NR	Saginaw Bay	NR	NR	16	
2,3',4,4',5,5'-HxCB (167)	Carp	Whole	1	1	77,000	77,000	NR	Saginaw Bay	NR	NR	16	
HxCBs	Various[c]	Mixed[d]	362	321	NR	355,930	Wet	Various, US	Various	86-89	20	composite 3-5 fish
Heptachloro-PCB (MW=396.33)												
2,3,3',4,4',5,5'-HpCB (189)	Carp	Whole	1	1	29,000	29,000	NR	Saginaw Bay	NR	NR	16	
HpCBs	Various[c]	Mixed[d]	362	250	NR	96,700	Wet	Various, US	Various	86-89	20	composite 3-5 fish

Footnote References

[a] Blk. = Black; Lg. M. = Large Mouth; Wh. = White; Y. = Yellow; Br. = Brown; Rb. = Rainbow

[b] US = samples taken from 362 sites across the US, including industrial and background sites.

[c] Species were taken from both bottom feeders and open water feeders, and then composited.

[d] Whole fish samples and fillet samples were combined for analysis.

Table B-11. Levels of Dioxins in Food Products (ppt)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzo-p-dioxins (MW=321.98)											
2,3,7,8-TCDD	Food basket	3	0	ND(0.1-0.4)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	1.4	1.4	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	0	ND(.012-.013)	NA	Whole	Switzerland	Background	NR	2	
	Milk	4	3	ND-0.049	0.027	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	0.2	0.2	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.08	0.08	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.03	0.03	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.2	0.2	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	4.7	4.7	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	23	23	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	2.8	2.8	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	1	1	0.0018	0.0018	Whole	U.S.		NR	4	
	Beef	3	3	0.017-0.062	0.032	Whole	U.S.		NR	4	
	Pork	3	0	ND(0.006)	NA	Whole	U.S.		NR	4	
	Milk	10	NR	ND-1.9	0.4	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	0	ND(0.5)	NA	Fat	W. Germany		NR	5	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Butter	5	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Beef	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Veal	4	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Sheep	2	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Chicken	2	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Canned meat	2	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Milk	7	NR	ND-0.013	0.009[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.13-0.18	0.16	Wet	Norwich, UK		NR	7	
	Mackerel, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.19	0.19	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	0.05	0.05	Wet	Norwich, UK		NR	7	
	Skate, whole	1	0	ND(0.16)	NA	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.06	0.06	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.15)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.03)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.34)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.72)	NA	Wet	USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Butter	1	0	ND(0.53)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.03)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.57)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	0	ND(0.34)	NA	Wet	South Vietnam		NR	8	
	Pork fat	1	0	ND(0.99)	NA	Wet	South Vietnam		NR	8	
	Chicken fat	1	0	ND(0.95)	NA	Wet	South Vietnam		NR	8	
	Milk	1	1	0.12[d]	0.12[d]	Whole	Vermont, U.S.	Background	87-88	9	
	Cottage cheese	1	0	ND(0.003)	NA	Wet	New York, NY		1990	10	
	Soft blue cheese	1	0	ND(0.05)	NA	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	0	ND(0.04)	NA	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.04	0.04	Wet	New York, NY		1990	10	
	American cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.12-0.41)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Beef	3	0	ND(0.16-0.40)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Pork	5	0	ND(0.07-0.52)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Pork	3	0	ND(0.39-0.49)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Chicken	5	2	ND-0.43	0.23	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Chicken	3	1	ND-1.67	0.70	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Eggs	5	0	ND(0.01-0.03)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples
	Eggs	3	0	ND(0.01-0.03)	NA	Whole	San Francisco	Urban	NR	11	Composite 6 samples

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	Beef	3	3	0.005-0.028	0.017	Wet	New York, NY		1990	12	
	Pork	1	1	0.013	0.013	Wet	New York, NY		1990	12	
	Chicken	1	1	0.011	0.011	Wet	New York, NY		1990	12	
Pentachlorodibenzo-p-dioxins (MW = 326.44)											
1,2,3,7,8-PeCDD	Food basket	3	0	ND(0.2-0.8)	NA	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	3.5	3.5	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	0	ND(0.04-0.06)	NA	Whole	Switzerland	Background	NR	2	
	Milk	4	2	ND-0.25	0.12	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	0.7	0.7	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.41	0.41	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.8	0.8	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.12	0.12	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.5	0.5	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.7	0.7	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.4	0.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	12	12	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	1.3	1.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	6.5	6.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	NR	ND-2.5	1.2	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-0.8	0.6	Fat	W. Germany		NR	5	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	Butter	5	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Beef	3	3	0.5-4.6	1.7	Fat	W. Germany		NR	5	
	Veal	4	4	2.5-3.4	3.1	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Sheep	2	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Chicken	2	2	0.9-1.2	1.0	Fat	W. Germany		NR	5	
	Canned meat	2	1	ND-0.9	0.6	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Milk	7	7	0.012-0.023	0.016[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.10-0.38	0.24	Wet	Norwich, UK		NR	7	
	Mackerel, whole	1	1	0.10	0.10	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.60	0.60	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.06)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Coley, whole	1	0	ND(0.04)	NA	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.17	0.17	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.50	0.50	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.95	0.95	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.01	0.01	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.2	0.2	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	0.11	0.11	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.11	0.11	Wet	New York, NY		1990	10	
	American cheese	1	1	0.12	0.12	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.40-17.50)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Beef	3	0	ND(0.49-1.09)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Pork	5	0	ND(1.00-4.36)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Pork	3	0	ND(1.94-2.70)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Chicken	5	0	ND(0.19-2.19)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Chicken	3	0	ND(0.44-7.40)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Eggs	5	0	ND(0.06-0.40)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples
	Eggs	3	0	ND(0.04-0.06)	NA	Whole	San Francisco	Urban	NR	11	Composite 6 samples
	Beef	3	3	0.01 - 0.208	0.093	Wet	New York, NY		1990	12	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	Pork	1	1	0.041	0.041	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.011)	NA	Wet	New York, NY		1990	12	
PeCDDs	Cottage cheese	1	1	0.6	0.6	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	14	14	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	5	5	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	4	4	Wet	New York, NY		1990	10	
	American cheese	1	1	4	4	Wet	New York, NY		1990	10	
Hexachlorodibenzo-p-dioxins (MW = 390.87)											
1,2,3,4,7,8-HxCDD	Food basket	3	0	ND(0.4-1.6)	NA	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	0.47	0.47	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.068	0.049	Whole	Switzerland	Background	NR	2	
	Milk	4	3	ND-0.23	0.14	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	0.3	0.3	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.15	0.15	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.21	0.21	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.5	0.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	1.3	1.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	1.2	1.2	Fat	Berlin, W. Germany	Urban	NR	3	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDD (continued)	Cod	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	0.5	0.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	NR	ND-2.0	0.8	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	0.2-0.4	0.3	Fat	W. Germany		NR	5	
	Butter	5	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Beef	3	3	0.5-4.6	1.9	Fat	W. Germany		NR	5	
	Veal	4	4	1.1-3.0	1.9	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Sheep	2	2	0.7-1.0	0.8	Fat	W. Germany		NR	5	
	Chicken	2	1	ND-0.8	0.6	Fat	W. Germany		NR	5	
	Canned meat	2	1	ND-2.1	1.0	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.012	0.012	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDD (continued)	Pork sticks	1	1	0.24	NA	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.60	NA	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.48	NA	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.02	0.02	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.29	0.29	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	American cheese	1	1	0.017	0.017	Wet	New York, NY		1990	10	
	Eggs	5	0	ND(0.12-0.67)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples
	Eggs	3	0	ND(0.08-0.25)	NA	Whole	San Fransisco	Urban	NR	11	Composite 6 samples
	Chicken	1	0	ND(0.017)	NA	Wet	New York, NY		1990	12	
1,2,3,6,7,8-HxCDD	Food basket	3	0	ND(0.4-1.6)	NA	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	1.8	1.8	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.068	0.049	Whole	Switzerland	Background	NR	2	
	Milk	4	3	ND-0.29	0.18	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	1.1	1.1	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.95	0.95	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	1.9	1.9	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.29	0.29	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD (continued)	Chicken	1	1	2.8	2.8	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	1.4	1.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	5.8	5.8	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	17	17	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	8.4	8.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	0.5-10.0	4.0	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	0.4-1.2	0.8	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-1.0	0.7	Fat	W. Germany		NR	5	
	Beef	3	3	1.3-6.0	3.2	Fat	W. Germany		NR	5	
	Veal	4	4	3.3-8.0	5.3	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Sheep	2	2	2.3-3.7	3.0	Fat	W. Germany		NR	5	
	Chicken	2	2	1.7-1.8	1.8	Fat	W. Germany		NR	5	
	Canned meat	2	2	0.9-7.4	3.2	Fat	W. Germany		NR	5	
	Lard	4	NR	ND-0.6	0.3	Fat	W. Germany		NR	5	
	Cow cream	1	1	0.135	0.135	Wet	USSR		88-89	8	
	Beef	1	1	0.018	0.018	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.288	0.288	Wet	USSR		88-89	8	
	Beef fat	1	1	0.340	0.340	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD (continued)	Butter	1	1	0.318	0.318	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.048	0.048	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.47	0.47	Wet	South Vietnam		NR	8	
	Pork fat	1	1	1.69	1.69	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	3.8	3.8	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	1.72	1.72	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	0.7	0.7	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.58	0.58	Wet	New York, NY		1990	10	
	American cheese	1	1	0.38	0.38	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.74-2.72)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Beef	3	0	ND(1.64-4.08)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Pork	5	0	ND(0.64-3.60)	NA	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Pork	3	0	ND(1.06-2.92)	NA	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Chicken	5	1	ND-2.14	0.98	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Chicken	3	1	ND-4.30	1.84	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Eggs	5	0	ND(0.10-0.56)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples
	Eggs	3	0	ND(0.07-0.21)	NA	Whole	San Francisco	Urban	NR	11	Composite 6 samples
	Beef	3	3	0.03-1.981	0.84	Wet	New York, NY		1990	12	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD	Pork	1	1	0.282	0.282	Wet	New York, NY		1990	12	
(continued)	Chicken	1	1	0.04	0.04	Wet	New York, NY		1990	12	
1,2,3,7,8,9-HxCDD	Food basket	3	0	ND(0.5-1.6)	NA	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	0.25	0.25	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.068	0.049	Whole	Switzerland	Background	NR	2	
	Milk	4	3	ND-0.17	0.10	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	0.4	0.4	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.26	0.26	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.06	0.06	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.4	0.4	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.5	0.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	1.0	1.0	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	5.2	5.2	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	1.3	1.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	NR	ND-3.0	0.8	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	0.3-0.9	0.5	Fat	W. Germany		NR	5	
	Butter	5	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Beef	3	3	0.7-4.5	2.0	Fat	W. Germany		NR	5	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDD (continued)	Veal	4	4	1.2-3.0	1.8	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Sheep	2	NR	ND-1.1	0.7	Fat	W. Germany		NR	5	
	Chicken	2	2	0.5-0.6	0.6	Fat	W. Germany		NR	5	
	Canned meat	2	NR	ND-2.7	1.2	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.5)	NA	Fat	W. Germany		NR	5	
	Milk	7	NR	ND-0.018	0.010[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.02-0.05	0.04	Wet	Norwich, UK		NR	7	
	Mackerel, whole	1	1	0.02	0.02	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.02)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.04	0.04	Wet	Norwich, UK		NR	7	
	Coley, whole	1	0	ND(0.04)	NA	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.012	0.012	Wet	USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDD (continued)	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.10	0.10	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.40	0.40	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.67	0.67	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.02	0.02	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.29	0.29	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	American cheese	1	1	0.19	0.19	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.74-2.72)	NA	Fat	Los Angeles, CA		NR	11	
	Beef	3	0	ND(1.64-4.08)	NA	Fat	San Francisco, CA		NR	11	
	Pork	5	0	ND(0.64-3.6)	NA	Fat	Los Angeles,		NR	11	
	Pork	3	0	ND(1.06-2.92)	NA	Fat	San Francisco, CA		NR	11	
	Chicken	5	1	ND-2.14	NA	Fat	Los Angeles, CA		NR	11	
	Chicken	3	1	ND-4.30	NA	Fat	San Francisco, CA		NR	11	
	Beef	3	3	0.011-0.616	0.238	Wet	New York		1990	12	
	Pork	1	1	0.044	0.044	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.014)	NA	Wet	New York, NY		1990	12	
HxCDDs	Chicken fat	26	13	ND-67	27	Fat	Canada		80	6	
Heptachlorodibenzo-p-dioxins(MW = 425.31)											

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDD	Food basket	3	0	ND(0.4-1.7)	NA	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	0.45	0.45	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	2	0.064	0.064	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.066-0.42	0.21	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	2	2	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	18	18	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	2.1	2.1	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	15	15	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	6.0	6.0	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.4	0.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	3.6	3.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	10	10	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	3.0	3.0	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	1.0-29.0	6.2	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	1.2-4.0	2.3	Fat	W. Germany		NR	5	
	Butter	5	5	0.5-5.0	1.7	Fat	W. Germany		NR	5	
	Beef	3	3	1.8-6.7	3.9	Fat	W. Germany		NR	5	
	Veal	4	4	2.6-43.7	14.4	Fat	W. Germany		NR	5	
	Pork	3	NR	ND-1.6	0.7	Fat	W. Germany		NR	5	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDD (continued)	Sheep	2	2	10.9-11.8	11.4	Fat	W. Germany		NR	5	
	Chicken	2	2	4.5-5.0	4.5	Fat	W. Germany		NR	5	
	Canned meat	2	2	2.5-33.0	13.2	Fat	W. Germany		NR	5	
	Lard	4	4	2.0-3.0	2.8	Fat	W. Germany		NR	5	
	Milk	7	NR	ND-0.066	0.046[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.13-0.34	0.22	Wet	Norwich, UK		NR	7	
	Mackerel, whole	1	1	0.48	0.48	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.47	0.47	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.44)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.26	0.26	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.21	0.21	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	0.450	0.450	Wet	USSR		88-89	8	
	Beef	1	1	0.156	0.156	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.720	0.720	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	1	1.44	1.44	Wet	USSR		88-89	8	
	Butter	1	1	0.530	0.530	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.240	0.240	Wet	USSR		88-89	8	
	Sausage	1	1	0.57	0.57	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	2.84	2.84	Wet	South Vietnam		NR	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDD (continued)	Pork fat	1	1	7.44	7.44	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	13.3	13.3	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.18	0.18	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	5.88	5.88	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	2.11	2.11	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	1.51	1.51	Wet	New York, NY		1990	10	
	American cheese	1	1	1.13	1.13	Wet	New York, NY		1990	10	
	Beef	5	4	ND-6.71	4.48	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Beef	3	3	4.56-8.95	6.28	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Pork	5	5	3.32-45.50	14.74	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Pork	3	3	3.04-15.30	10.15	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Chicken	5	4	ND-35.20	9.64	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Chicken	3	3	1.10-11.40	4.62	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Eggs	5	0	ND(0.10-0.42)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples
	Eggs	3	0	ND(0.08-0.24)	NA	Whole	San Francisco	Urban	NR	11	Composite 6 samples
	Beef	3	3	0.117-12.065	4.45	Wet	New York, NY		1990	12	
	Pork	1	1	8.197	8.2	Wet	New York, NY		1990	12	
	Chicken	1	1	0.133	0.13	Wet	New York, NY		1990	12	
HpCDDs	Chicken fat	26	16	ND-142	52	Fat	Canada		1980	6	
Octachlorodibenzo-p-dioxin (MW=460.76)											

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD	Food basket	3	3	1.0-2.1	1.47	Fresh	Stockholm, Sweden	Urban	NR	1	
	Herring, fillet	1	1	0.34	0.34	Fresh	Baltic Sea, Sweden		1988	1	sample composite 12 fillets
	Milk	2	2	0.12-0.16	0.14	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.16-0.59	0.32	Whole	Switzerland	Industrial	NR	2	Near Incinerators
	Milk	1	1	10	10	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	3.4	3.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	25	25	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	19	19	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	68	68	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	52	52	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	12	12	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	19	19	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	83	83	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	11	11	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	4.3-25.0	11.0	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	5.0-17.0	10.5	Fat	W. Germany		NR	5	
	Butter	5	5	2.0-35.0	11.6	Fat	W. Germany		NR	5	
	Beef	3	3	4.7-6.0	5.4	Fat	W. Germany		NR	5	
	Veal	4	4	3.1-69.0	22.3	Fat	W. Germany		NR	5	
	Pork	3	3	5.4-12.3	8.2	Fat	W. Germany		NR	5	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	Sheep	2	2	14.4-24.4	19.3	Fat	W. Germany		NR	5	
	Chicken	2	2	14.0-19.0	16.5	Fat	W. Germany		NR	5	
	Canned meat	2	2	17.0-122	53.0	Fat	W. Germany		NR	5	
	Lard	4	4	10.0-23.0	16.0	Fat	W. Germany		NR	5	
	Chicken fat	26	12	ND-238	90	Fat	Canada		80	6	
	Milk	7	7	0.215-0.323	0.230[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	1.40-3.20	2.12	Wet	Norwich, UK		NR	7	
	Mackerel, whole	1	1	4.81	4.81	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	3.4	3.4	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	2.79	2.79	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	1.36	1.36	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	2.25	2.25	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	3.15	3.15	Wet	USSR		88-89	8	
	Beef	1	1	0.63	0.63	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	5.40	5.40	Wet	USSR		88-89	8	
	Beef fat	1	1	3.40	3.40	Wet	USSR		88-89	8	
	Pork	1	1	11.5	11.5	Wet	USSR		88-89	8	
	Butter	1	1	9.01	9.01	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.660	0.660	Wet	USSR		88-89	8	
	Sausage	1	1	5.70	5.70	Wet	Moscow, USSR		88-89	8	

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	Pork sticks	1	1	9.46	9.46	Wet	South Vietnam		NR	8	
	Pork fat	1	1	29.8	29.8	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	22.8	22.8	Wet	South Vietnam		NR	8	
	Swiss cheese	1	1	0.66	0.66	Wet	USSR		88-89	8	
	Sausage	1	1	5.7	5.7	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	9.46	9.46	Wet	South Vietnam		NR	8	
	Pork fat	1	1	29.8	29.8	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	22.8	22.8	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.34	0.34	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	5.93	5.93	Wet	New York, NY		1990	10	
	Heavy cream cheese	1	1	1.54	1.54	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	1.5	1.5	Wet	New York, NY		1990	10	
	American cheese	1	1	1.6	1.6	Wet	New York, NY		1990	10	
	Beef	5	4	ND-11.40	8.58	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Beef	3	3	8.03-11.90	9.43	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Pork	5	5	13.70-254.00	77.20	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Pork	3	3	24.90-125.00	72.43	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Chicken	5	4	ND-64.00	28.97	Fat	Los Angeles	Urban	NR	11	Composite 6 samples
	Chicken	3	3	2.61-96.20	35.01	Fat	San Francisco	Urban	NR	11	Composite 6 samples
	Eggs	5	0	ND(0.80-1.60)	NA	Whole	Los Angeles	Urban	NR	11	Composite 6 samples

Table B-11. Levels of Dioxins in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. Mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	Eggs	3	1	ND-1.30	0.63	Whole	San Francisco	Urban	NR	11	Composite 6 samples
	Beef	3	3	0.414-15.825	6.167	Wet	New York, NY		1990	12	
	Pork	1	1	50.742	50.7	Wet	New York, NY		1990	12	
	Chicken	1	1	0.74	0.74	Wet	New York, NY		1990	12	

Footnote references

[a] Samples were obtained from grocery stores unless stated otherwise. Milk samples were obtained from dairies or transport trucks. No cooked samples from the references were used.
[b] For ND values 1/2 LOD was used in calculating the mean. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).
[c] For ND values the detection limit was used in calculating the mean.
[d] Value in reference was reported as total 2,3,7,8-TCDD toxic equivalents.

NR = not reported
NA = not applicable

Sources:
1. de Wit et al. (1990)
2. Rappe et al. (1987)
3. Beck et al. (1989)
4. LaFleur et al. (1990)
5. Furst et al. (1990)
6. Ryan et al. (1985)
7. Startin et al. (1990)
8. Schecter et al. (1990)
9. U.S. EPA (1991)
10. Schecter et al. (1992)
11. Stanley and Bauer (1989)
12. Schecter et al. (1993)

Table B-12. Levels of Dibenzofurans in Food Products (ppt)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzofurans (MW=305.98)											
2,3,7,8-TCDF	Food basket	3	3	0.1-0.4	2.3	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	7.6	7.6	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	2	0.021-0.028	0.024	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.022-0.035	0.029	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.7	0.7	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.15	0.15	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.11	0.11	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	2.1	2.1	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	1.1	1.1	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	57	57	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	98	98	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	78	78	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	1	0	ND(0.001)	NA	Whole	U.S.		NR	4	
	Beef	3	1	ND-0.005	0.0032	Whole	U.S.		NR	4	
	Pork	3	3	0.013-0.020	0.015	Whole	U.S.		NR	4	
	Milk	10	NR	ND-10.0	4.1	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-2.6	1.1	Fat	W. Germany		NR	5	
	Butter	5	0	ND(0.3)	NA	Fat	W. Germany		NR	5	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Beef	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Veal	4	NR	ND-0.5	0.2	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Chicken	2	2	1.2-4.0	2.6	Fat	W. Germany		NR	5	
	Canned meat	2	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Lard	4	NR	ND-1.0	0.5	Fat	W. Germany		NR	5	
	Milk	7	NR	ND-0.011	0.008[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.90-1.86	1.32	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	2.61	2.61	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	2.47	2.47	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	0.22	0.22	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.31	0.31	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.14	0.14	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	0.285	0.285	Wet	USSR		88-89	8	
	Beef	1	1	0.027	0.027	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.108	0.108	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	1	0.288	0.288	Wet	USSR		88-89	8	
	Butter	1	1	0.212	0.212	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.021	0.021	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.17)	NA	Wet	Moscow, USSR		88-89	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDF (continued)	Pork sticks	1	1	0.34	0.34	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.50	0.50	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	1.9	1.9	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.02	0.02	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.15	0.15	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	American cheese	1	1	0.1	0.1	WEt	New York, NY		1990	10	
	Beef	5	1	ND-0.84	0.28	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	2	ND-1.56	0.78	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.22-0.49)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.35-0.54)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.19-0.58)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	1	ND-0.67	0.33	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.01-0.03)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	1	ND-0.01	0.01	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	0.01-0.051	0.029	Wet	New York, NY		1990	12	
	Pork	1	1	0.065	0.065	Wet	New York, NY		1990	12	
	Chicken	1	1	0.032	0.032	Wet	New York, NY		1990	12	
Pentachlorodibenzofurans (MW=340.42)											
1,2,3,7,8-PeCDF	Food basket	3	0	ND(0.1-0.4)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	4.2	4.2	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDF (continued)	Milk	2	2	0.020-0.021	0.020	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.020-0.036	0.028	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.2	0.2	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.09	0.09	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.01	0.01	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	16	16	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	48	48	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	31	31	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	NR	ND-1.3	0.3	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-0.3	0.2	Fat	W. Germany		NR	5	
	Butter	5	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Beef	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Veal	4	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Chicken	2	1	ND-1.2	0.7	Fat	W. Germany		NR	5	
	Canned meat	2	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Lard	4	NR	ND-0.3	0.2	Fat	W. Germany		NR	5	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDF (continued)	Milk	7	0	ND(.002-.017)	0.005[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.14-0.23	0.18	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.08	0.08	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.47	0.47	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	0.05	0.05	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	0.165	0.165	Wet	USSR		88-89	8	
	Beef	1	1	0.006	0.006	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	1	0.144	0.144	Wet	USSR		88-89	8	
	Butter	1	1	0.212	0.212	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.006	0.006	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.17)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.14	0.14	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.20	0.20	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.48	0.48	Wet	South Vietnam		NR	8	
	Cottage cheese	1	0	ND(0.003)	NA	Wet	New York, NY		1990	10	
	Soft blue cheese	1	0	ND(0.05)	NA	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	0	ND(0.04)	NA	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.04	0.04	Wet	New York, NY		1990	10	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDF (continued)	American cheese	1	0	ND(0.05)	NA	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.25-0.86)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.10-1.44)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.37-1.40)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.28-0.58)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.16-0.67)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.12-0.15)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.03-0.10)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.01-0.02)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	1	ND-0.01	NA	Wet	New York, NY		1990	12	
	Pork	1	1	0.009	0.009	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.006)	NA	Wet	New York, NY		1990	12	
	Beef	3	1	ND-0.01	NA	Wet	New York, NY		1990	12	
	Pork	1	1	0.009	0.009	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.006)	NA	Wet	New York, NY		1990	12	
2,3,4,7,8-PeCDF	Food basket	3	0	ND(0.1-0.5)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	17.0	17.0	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	2	0.069-0.084	0.076	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.066-0.43	0.24	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	1.4	1.4	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.45	0.45	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	Pork	1	1	0.08	0.08	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.9	0.9	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.8	0.8	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	29	29	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	3.1	3.1	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	25	25	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	1.7-4.6	2.7	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	0.9-2.5	1.7	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-2.0	1.1	Fat	W. Germany		NR	5	
	Beef	3	3	1.7-3.9	2.7	Fat	W. Germany		NR	5	
	Veal	4	4	6.5-8.2	7.4	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	2	0.7-2.8	1.7	Fat	W. Germany		NR	5	
	Chicken	2	2	0.7-2.0	1.3	Fat	W. Germany		NR	5	
	Canned meat	2	2	0.3-1.3	0.8	Fat	W. Germany		NR	5	
	Lard	4	NR	ND-0.4	0.3	Fat	W. Germany		NR	5	
	Milk	7	7	0.028-0.038	0.032[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.39-1.58	0.95	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.37	0.37	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	1.96	1.96	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	0.03	0.03	Wet	Norwich, UK		NR	7	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	Skate, whole	1	0	ND(0.04)	NA	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.04	0.04	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	1.10	1.10	Wet	USSR		88-89	8	
	Beef	1	1	0.177	0.177	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.108	0.108	Wet	USSR		88-89	8	
	Beef fat	1	1	0.204	0.204	Wet	USSR		88-89	8	
	Pork	1	1	0.504	0.504	Wet	USSR		88-89	8	
	Butter	1	1	1.43	1.43	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.015	0.015	Wet	USSR		88-89	8	
	Sausage	1	1	0.171	0.171	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.27	0.27	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.99	0.99	Wet	South Vietnam		NR	8	
	Chicken fat										
	Cottage cheese	1	1	0.02	0.02	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.25	0.25	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.18	0.18	Wet	New York, NY		1990	10	
	American cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.22-0.78)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.28-1.31)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.33-1.28)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.26-0.53)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	Chicken	5	0	ND(0.15-0.60)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.11-0.14)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.01-0.07)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.02-0.02)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	0.03-1.783	0.626	Wet	New York, NY		1990	12	
	Pork	1	1	0.039	0.039	Wet	New York, NY		1990	12	
	Chicken	1	1	0.01	0.01	Wet	New York, NY		1990	12	
PeCDFs	Cottage cheese	1	1	0.3	0.03	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	5	5	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	2	2	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	2	2	Wet	New York, NY		1990	10	
	American cheese	1	1	2	2	Wet	New York, NY		1990	10	
Hexachlorodibenzofurans (MW=374.87)											
1,2,3,4,7,8-HxCDF	Milk	2	2	0.017-0.020	0.018	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.026-0.13	0.075	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.9	0.9	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.43	0.43	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.8	0.8	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.15	0.15	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.9	0.9	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.4	0.4	Fat	Berlin, W. Germany	Urban	NR	3	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	Herring	1	1	3.0	3.0	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	6.9	6.9	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	3.5	3.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	0.7-3.0	1.7	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-2.6	0.8	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-1.0	0.7	Fat	W. Germany		NR	5	
	Beef	3	NR	ND-1.1	0.7	Fat	W. Germany		NR	5	
	Veal	4	4	1.8-6.0	2.9	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	1	ND-1.4	0.8	Fat	W. Germany		NR	5	
	Chicken	2	1	ND-1.9	1.0	Fat	W. Germany		NR	5	
	Canned meat	2	2	0.6-0.9	0.8	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Milk	7	7	0.013-0.026	0.017[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.05-0.16	0.11	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	0	ND(0.02)	NA	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.12	0.12	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.1)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.04	0.04	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.03	0.03	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	1.05	1.05	Wet	USSR		88-89	8	
	Beef	1	1	0.141	0.141	Wet	USSR		88-89	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	Cheese w/butter	1	1	0.108	0.108	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	1	0.432	0.432	Wet	USSR		88-89	8	
	Butter	1	1	2.01	2.01	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.009	0.009	Wet	USSR		88-89	8	
	Sausage	1	1	0.171	0.171	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.27	0.27	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.79	0.79	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.48	0.48	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.06	0.06	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.93	0.93	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.47	0.47	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.43	0.43	Wet	New York, NY		1990	10	
	American cheese	1	1	0.36	0.36	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.38-1.19)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.35-0.79)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.49-3.40)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.40-3.33)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.35-0.59)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.51-0.71)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.14-0.25)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.04-0.09)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	Beef	3	3	0.066-4.846	1.69	Wet	New York, NY		1990	12	
	Pork	1	1	0.108	0.108	Wet	New York, NY		1990	12	
	Chicken	1	1	0.009	0.009	Wet	New York, NY		1990	12	
1,2,3,6,7,8-HxCDF	Food basket	3	0	ND(0.1-0.8)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	1.7	1.7	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	2	0.021-0.028	0.024	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.018-0.19	0.090	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.8	0.8	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.44	0.44	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.07	0.07	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	1.2	1.2	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.4	0.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	4.2	4.2	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	13	13	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	6.0	6.0	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	0.5-2.0	1.1	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-0.9	0.5	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-1.0	0.7	Fat	W. Germany		NR	5	
	Beef	3	NR	ND-0.9	0.5	Fat	W. Germany		NR	5	
	Veal	4	4	1.3-5.0	2.4	Fat	W. Germany		NR	5	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDF (continued	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	1	ND-1.0	0.6	Fat	W. Germany		NR	5	
	Chicken	2	2	0.3-0.8	0.5	Fat	W. Germany		NR	5	
	Canned meat	2	1	ND-0.7	0.5	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Milk	7	7	0.009-0.017	0.012[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.02-0.06	0.04	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.06	0.06	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.16	0.16	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.1)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.05	0.05	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.06	0.06	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	0.240	0.240	Wet	USSR		88-89	8	
	Beef	1	1	0.030	0.030	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.108	0.108	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	1	0.144	0.144	Wet	USSR		88-89	8	
	Butter	1	1	0.424	0.424	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.009	0.009	Wet	USSR		88-89	8	
	Sausage	1	1	0.171	0.171	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.14	0.14	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.40	0.40	Wet	South Vietnam		NR	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDF (continued)	Chicken fat	1	1	0.38	0.38	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.02	0.02	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.34	0.34	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.18	0.18	Wet	New York, NY		1990	10	
	American cheese	1	1	0.1	0.1	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.37-1.17)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.35-0.77)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.48-0.81)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.39-0.84)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.35-0.56)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.14-0.70)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.14-0.31)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.04-0.05)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	ND-0.199	NA	Wet	New York	1990	1990	12	
	Pork	1	1	0.031	0.031	Wet	New York		1990	12	
	Chicken	1	1	0.008	0.008	Wet	New York		1990	12	
	Food basket	3	0	ND(0.1-0.3)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	0	ND(0.04)	NA	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	7	0	ND(.002-.012)	0.008[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	1	ND-0.02	0.015	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	0	ND(0.04)	NA	Wet	Norwich, UK		NR	7	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDF (continued)	Herring, whole	1	0	ND(0.05)	NA	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.1)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	0	ND(0.05)	NA	Wet	Norwich, UK		NR	7	
	Coley, whole	1	0	ND(0.04)	NA	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.04)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.01)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.11)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.14)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.16)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.01)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.11)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	0	ND(0.1)	NA	Wet	South Vietnam		NR	8	
	Pork fat	1	0	ND(0.2)	NA	Wet	South Vietnam		NR	8	
	Chicken fat	1	0	ND(0.19)	NA	Wet	South Vietnam		NR	8	
	Cottage cheese	1	0	ND(0.006)	NA	Wet	New York, NY		1990	10	
	Soft blue cheese	1	0	ND(0.1)	NA	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	0	ND(0.04)	NA	Wet	New York, NY		1990	10	
	Soft cream cheese	1	0	ND(0.04)	NA	Wet	New York, NY		1990	10	
	American cheese	1	0	ND(0.05)	NA	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.48-1.51)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.45-1.01)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDF (continued)	Pork	5	0	ND(0.62-1.06)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.51-1.09)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.45-0.75)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.18-0.91)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.18-0.58)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.05-0.06)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.002-0.01)	NA	Wet	New York, NY		1990	12	
	Pork	1	0	ND(0.007)	NA	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.012)	NA	Wet	New York, NY		1990	12	
2,3,4,6,7,8-HxCDF	Food basket	3	0	ND(0.1-0.5)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	3.9	3.9	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.020	0.015	Whole	Switzerland	Background	NR	2	
	Milk	4	4	0.018-0.28	0.12	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.7	0.7	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.31	0.31	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	1.3	1.3	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.05	0.05	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	1.7	1.7	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	3.6	3.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	8.2	8.2	Fat	Berlin, W. Germany	Urban	NR	3	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
2,3,4,6,7,8-HxCDF (continued)	Redfish	1	1	7.2	7.2	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	0.7-2.2	1.3	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-1.1	0.7	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-1.0	0.7	Fat	W. Germany		NR	5	
	Beef	3	NR	ND-1.5	0.9	Fat	W. Germany		NR	5	
	Veal	4	4	1.7-5.0	2.8	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	1	ND-0.9	0.5	Fat	W. Germany		NR	5	
	Chicken	2	1	ND-1.2	0.7	Fat	W. Germany		NR	5	
	Canned meat	2	1	ND-0.6	0.4	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Milk	7	7	0.007-0.017	0.012[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.04-0.13	0.08	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.03	0.03	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.15	0.15	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.1)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.04	0.04	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.03	0.03	Wet	Norwich, UK		NR	7	
	Cow cream	1	1	0.060	0.060	Wet	USSR		88-89	8	
	Beef	1	1	0.009	0.009	Wet	USSR		88-89	8	
	Cheese w/butter	1	1	0.072	0.072	Wet	USSR		88-89	8	
2,3,4,6,7,8-HxCDF	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
(continued)	Pork	1	1	0.144	0.144	Wet	USSR		88-89	8	
	Butter	1	1	0.159	0.159	Wet	USSR		88-89	8	
	Swiss cheese	1	1	0.006	0.006	Wet	USSR		88-89	8	
	Sausage	1	1	0.114	0.114	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.10	0.10	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.20	0.20	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.19	0.19	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.01	0.01	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	0.15	0.15	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.11	0.11	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	American cheese	1	1	0.07	0.07	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.44-1.39)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.41-0.92)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(0.57-0.97)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	0	ND(0.47-1.00)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.41-0.69)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.17-0.84)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.16-0.52)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.04-0.05)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	0.01-0.177	0.075	Wet	New York, NY		1990	12	
	Pork	1	1	0.019	0.019	Wet	New York, NY		1990	12	

Table B-12. *Levels of Dibenzofurans in Food Products (ppt) (continued)*

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Chicken	1	0	ND(0.01)	NA	Wet	New York, Ny		1990	12	
Heptachlorodibenzofuran(MW=409.31)											
1,2,3,4,6,7,8-HpCDF	Food basket	3	0	ND(0.2-0.9)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	1	0.38	0.38	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.12	0.08	Whole	Switzerland	Background	NR	2	
	Milk	4	3	ND-0.49	0.25	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	0.5	0.5	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.34	0.34	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	2.2	2.2	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	1.1	1.1	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	8.1	8.1	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.8	0.8	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	1.6	1.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	10	10	Fat	Berlin, W. Germany	Urban	NR	3	
	Redfish	1	1	1.5	1.5	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	10	0.2-6.0	1.5	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	NR	ND-1.1	0.5	Fat	W. Germany		NR	5	
	Butter	5	NR	ND-1.0	0.3	Fat	W. Germany		NR	5	
	Beef	3	NR	ND-5.1	2.0	Fat	W. Germany		NR	-5	
	Veal	4	4	0.7-4.0	1.7	Fat	W. Germany		NR	5	
	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Sheep	2	2	0.6-1.4	1.0	Fat	W. Germany		NR	5	
1,2,3,4,6,7,8-HpCDF (continued)	Chicken	2	2	0.5-0.5	0.5	Fat	W. Germany		NR	5	
	Canned meat	2	2	0.9-1.9	1.2	Fat	W. Germany		NR	5	
	Lard	4	NR	ND-0.5	0.2	Fat	W. Germany		NR	5	
	Milk	7	0	ND(.007-.067)	0.020[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.04-0.10	0.07	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.07	0.07	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.14	0.14	Wet	Norwich, UK		NR	7	
	Cod, whole	1	0	ND(0.2)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.06	0.06	Wet	Norwich, UK		NR	7	
	Coley, whole	1	1	0.05	0.05	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.10	0.10	Wet	South Vietnam		NR	8	
	Pork fat	1	1	0.40	0.40	Wet	South Vietnam		NR	8	
	Chicken fat	1	1	0.38	0.38	Wet	South Vietnam		NR	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Cottage cheese	1	1	0.1	0.1	Wet	New York, NY		1990	10	
1,2,3,4,6,7,8-HpCDF (continued)	Soft blue cheese	1	1	1.76	1.76	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.6	0.6	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.58	0.58	Wet	New York, NY		1990	10	
	American cheese	1	1	0.52	0.52	Wet	New York, NY		1990	10	
	Beef	5	3	ND-1.15	0.96	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	1	ND-0.67	0.74	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	4	ND-10.60	4.05	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	3	2.09-5.68	3.55	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	5	1.57-24.60	7.00	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	1	ND-1.01	0.51	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.06-0.77)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	1	ND-0.07	0.05	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	0.018-2.702	1	Wet	New York, NY		1990	12	
	Pork	1	1	1.251	1.251	Wet	New York, NY		1990	12	
	Chicken	1	1	0.024	0.024	Wet	New York, NY		1990	12	
1,2,3,4,7,8,9-HpCDF	Food basket	3	0	ND(0.3-1.6)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	0	ND(0.04)	NA	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	7	0	ND(0.01-.067)	0.026[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	1	ND-0.02	0.03	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	0	ND(0.08)	NA	Wet	Norwich, UK		NR	7	
	Herring, whole	1	0	ND(0.06)	NA	Wet	Norwich, UK		NR	7	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Cod, whole	1	0	ND(0.2)	NA	Wet	Norwich, UK		NR	7	
	Skate, whole	1	0	ND(0.13)	NA	Wet	Norwich, UK		NR	7	
	Coley, whole	1	0	ND(0.10)	NA	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
1,2,3,4,7,8,9-HpCDF	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
(continued)	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	0	ND(0.07)	NA	Wet	South Vietnam		NR	8	
	Pork fat	1	0	ND(0.3)	NA	Wet	South Vietnam		NR	8	
	Chicken fat	1	0	ND(0.19)	NA	Wet	South Vietnam		NR	8	
	Cottage cheese	1	0	ND(0.03)	NA	Wet	New York, NY		1990	10	
	Soft blue cheese	1	0	ND(0.34)	NA	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.14	0.14	Wet	New York, NY		1990	10	
	Soft cream cheese	1	0	ND(0.18)	NA	Wet	New York, NY		1990	10	
	American cheese	1	0	ND(0.12)	NA	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.37-3.28)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.78-2.37)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	0	ND(2.22-5.40)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Pork	3	0	ND(1.63-3.12)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	0	ND(0.47-4.10)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.45-0.75)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.09-1.10)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.04-0.18)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	2	ND-0.118	NA	Wet	New York, NY		1990	12	
	Pork	1	1	0.097	0.097	Wet	New York, NY		1990	12	
	Chicken	1	0	ND(0.01)	NA	Wet	New York, NY		1990	12	
Octachlorodibenzofurans (MW=444.76)											
1,2,3,4,6,7,8,9-OCDF	Food basket	3	0	ND(0.4-2.1)	NA	Fresh	Sweden	Urban	NR	1	
	Herring, fillet	1	0	ND(0.07)	NA	Fresh	Baltic Sea, Sweden		88	1	sample composite 12 fillets
	Milk	2	1	ND-0.20	0.12	Whole	Switzerland	Background	NR	2	
	Milk	4	1	ND-0.52	0.19	Whole	Switzerland	Industrial	NR	2	near incinerators
	Milk	1	1	1	1	Fat	W. Germany		NR	3	composite from 8 trucks
	Butter	1	1	0.25	0.25	Fat	Berlin, W. Germany	Urban	NR	3	
	Beef fat	1	1	0.2	0.2	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Pork	1	1	0.41	0.41	Fat	Berlin, W. Germany	Urban	NR	3	
	Sheep fat	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	from slaughterhouse
	Chicken	1	1	0.6	0.6	Fat	Berlin, W. Germany	Urban	NR	3	
	Eggs	1	1	0.2	0.2	Fat	Berlin, W. Germany	Urban	NR	3	
	Herring	1	1	1.4	1.4	Fat	Berlin, W. Germany	Urban	NR	3	
	Cod	1	1	2.1	2.1	Fat	Berlin, W. Germany	Urban	NR	3	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Redfish	1	1	0.3	0.3	Fat	Berlin, W. Germany	Urban	NR	3	
	Milk	10	NR	ND-4.3	1.2	Fat	W. Germany		NR	5	samples not randomly selected
	Cheese	10	10	0.4-4.2	1.2	Fat	W. Germany		NR	5	
	Butter	5	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Beef	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Veal	4	NR	ND-5.0	1.4	Fat	W. Germany		NR	5	
1,2,3,4,6,7,8,9-OCDF (continued)	Pork	3	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Sheep	2	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Chicken	2	2	0.6-1.5	1.0	Fat	W. Germany		NR	5	
	Canned meat	2	2	0.3-2.7	1.3	Fat	W. Germany		NR	5	
	Lard	4	0	ND(0.3)	NA	Fat	W. Germany		NR	5	
	Milk	7	7	0.023-0.071	0.041[c]	Whole	England & Wales	Rural	89	7	
	Plaice, whole	3	3	0.08-0.23	0.16	Wet	Norwich, UK		NR	7	
	Mackeral, whole	1	1	0.20	0.20	Wet	Norwich, UK		NR	7	
	Herring, whole	1	1	0.19	0.19	Wet	Norwich, UK		NR	7	
	Cod, whole	1	1	0.26	0.26	Wet	Norwich, UK		NR	7	
	Skate, whole	1	1	0.14	0.14	Wet	Norwich, UK		NR	7	
	Coley, whole	1	0	ND(0.30)	NA	Wet	Norwich, UK		NR	7	
	Cow cream	1	0	ND(0.07)	NA	Wet	USSR		88-89	8	
	Beef	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Cheese w/butter	1	0	ND(0.18)	NA	Wet	USSR		88-89	8	
	Beef fat	1	0	ND(0.17)	NA	Wet	USSR		88-89	8	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Pork	1	0	ND(0.36)	NA	Wet	USSR		88-89	8	
	Butter	1	0	ND(0.26)	NA	Wet	USSR		88-89	8	
	Swiss cheese	1	0	ND(0.02)	NA	Wet	USSR		88-89	8	
	Sausage	1	0	ND(0.29)	NA	Wet	Moscow, USSR		88-89	8	
	Pork sticks	1	1	0.10	0.10	Wet	South Vietnam		NR	8	
	Pork fat	1	0	ND(0.3)	NA	Wet	South Vietnam		NR	8	
1,2,3,4,6,7,8,9-OCDF (continued)	Chicken fat	1	1	0.57	0.57	Wet	South Vietnam		NR	8	
	Cottage cheese	1	1	0.06	0.06	Wet	New York, NY		1990	10	
	Soft blue cheese	1	1	1.08	1.08	Wet	New York, NY		1990	10	
	Heavy Cream cheese	1	1	0.29	0.29	Wet	New York, NY		1990	10	
	Soft cream cheese	1	1	0.29	0.29	Wet	New York, NY		1990	10	
	American cheese	1	1	0.3	0.03	Wet	New York, NY		1990	10	
	Beef	5	0	ND(0.48-5.31)	NA	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Beef	3	0	ND(0.45-2.15)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Pork	5	4	ND-9.36	2.90	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Pork	3	1	ND-1.89	1.20	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Chicken	5	2	ND-26.00	6.64	Fat	Los Angeles	Urban	NR	11	composite 6 samples
	Chicken	3	0	ND(0.64-0.77)	NA	Fat	San Francisco	Urban	NR	11	composite 6 samples
	Eggs	5	0	ND(0.10-1.30)	NA	Whole	Los Angeles	Urban	NR	11	composite 6 samples
	Eggs	3	0	ND(0.05-0.21)	NA	Whole	San Francisco	Urban	NR	11	composite 6 samples
	Beef	3	3	0.018-1.073	0.381	Wet	New York, NY		1990	12	
	Pork	1	1	0.821	0.821	Wet	New York, NY		1990	12	

Table B-12. Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Concentration range	Conc. mean[b]	Wt. basis	Location	Location description	Sample year	Ref. no.	Comments
	Chicken	1	1	0.034	0.034	Wet	New York, NY		1990	12	

Footnote references

[a] Samples were obtained from grocery stores unless stated otherwise. Milk samples were obtained from dairies or transport trucks. No cooked samples from the references were used.
[b] For ND values 1/2 LOD was used in calculating the mean. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).
[c] For ND values the detection limit was used in calculating the mean.

NR = not reported.
NA = not applicable.

Sources: 1. de Wit et al. (1990)
2. Rappe et al. (1987)
3. Beck et al. (1989)
4. LaFleur et al. (1990)
5. Furst et al. (1990)
6. Ryan et al. (1985)
7. Startin et al. (1990)
8. Schecter et al. (1990)
9. U.S. EPA (1990)
10. Schecter et al. (1992)
11. Stanley and Bauer (1989)
12. Schecter et al. (1993)

Table B-13. Environmental Levels of PCBs in Food (ppt)

IUPAC number	Chemical	Sample Type	Number samples	Number positive samples	Concentration range	Conc. mean[a]	Location	Location description	Sample year	Ref. no.	Comments
Pentachloro-PCB (MW=326.44)											
105	2,3,3',4,4'-PeCB	Steak	1	1	NR	19	Canada	Urban	86-88	1	
		Roast Beef	3	3	NR	10	Canada	Urban	86-88	1	
		Ground Beef	2	2	NR	32	Canada	Urban	86-88	1	
		Pork	1	1	NR	54	Canada	Urban	86-88	1	
		Poultry	4	4	NR	25	Canada	Urban	86-88	1	
		Eggs	4	4	NR	34	Canada	Urban	86-88	1	
		Cream	3	3	NR	17	Canada	Urban	86-88	1	
		Ice cream	4	4	NR	16	Canada	Urban	86-88	1	
		Yogurt	1	1	NR	10	Canada	Urban	86-88	1	
		Cheese	5	5	NR	61	Canada	Urban	86-88	1	
		Cottage cheese	3	3	NR	13	Canada	Urban	86-88	1	
		Processed cheese	5	5	NR	49	Canada	Urban	86-88	1	
		Butter	4	4	NR	116	Canada	Urban	86-88	1	
118	2,3',4,4',5-PeCB	Steak	5	5	NR	56	Canada	Urban	86-88	1	
		Roast Beef	5	5	NR	38	Canada	Urban	86-88	1	
		Ground Beef	5	5	NR	119	Canada	Urban	86-88	1	

Table B-13 Environmental Levels of PCBs in Food Products (ppt) (continued)

IUPAC number	Chemical	Sample Type	Number samples	Number positive samples	Concentration range	Conc. mean[a]	Location	Location description	Sample year	Ref. no.	Comments
118	2,3',4,4',5-PeCB (continued)	Pork	4	4	NR	55	Canada	Urban	86-88	1	
		Poultry	4	4	NR	81	Canada	Urban	86-88	1	
		Eggs	5	5	NR	99	Canada	Urban	86-88	1	
		Margarine	1	1	NR	19	Canada	Urban	86-88	1	
		Cream	5	5	NR	72	Canada	Urban	86-88	1	
		Ice cream	5	5	NR	53	Canada	Urban	86-88	1	
		Yogurt	5	5	NR	24	Canada	Urban	86-88	1	
		Cheese	5	5	NR	251	Canada	Urban	86-88	1	
		Cottage cheese	5	5	NR	33	Canada	Urban	86-88	1	
		Processed cheese	5	5	NR	184	Canada	Urban	86-88	1	
		Butter	5	5	NR	487	Canada	Urban	86-88	1	
Hexachloro-PCB (MW=360.88)											
156	2,3,3',4,4',5-HxCB	Steak	2	2	NR	8	Canada	Urban	86-88	1	
		Ground Beef	4	4	NR	14	Canada	Urban	86-88	1	
		Pork	2	2	NR	9	Canada	Urban	86-88	1	
		Poultry	3	3	NR	16	Canada	Urban	86-88	1	
		Eggs	3	3	NR	24	Canada	Urban	86-88	1	
		Cream	2	2	NR	9	Canada	Urban	86-88	1	
		Ice cream	2	2	NR	9	Canada	Urban	86-88	1	

Table B-13 Environmental Levels of PCBs in Food Products (ppt) (continued)

IUPAC number	Chemical	Sample Type	Number samples	Number positive samples	Concentration range	Conc. mean[a]	Location	Location description	Sample year	Ref. no.	Comments
156	2,3,3',4,4',5-HxCB (continued)	Yogurt	1	1	NR	7	Canada	Urban	86-88	1	
		Cheese	5	5	NR	28	Canada	Urban	86-88	1	
		Cottage cheese	1	1	NR	13	Canada	Urban	86-88	1	
		Processed cheese	5	5	NR	22	Canada	Urban	86-88	1	
		Butter	5	5	NR	63	Canada	Urban	86-88	1	
Heptachloro-PCB (MW=396.33)											
189	2,3,3',4,4',5,5'-HpCB	Roast beef	1	1	NR	10	Canada	Urban	86-88	1	
		Cream	1	1	NR	10	Canada	Urban	86-88	1	
		Butter	1	1	NR	7	Canada	Urban	86-88	1	

Footnote References

[a] The mean is the geometric mean.

NR = Not Reported

Sources: 1. Mes, et al. (1991).

Table B-14. Environmental Levels of Dioxins in Air (pg/m³)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzo-p-dioxins (MW=321.98)									
2,3,7,8-TCDD	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	ND(0.01)	NA	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.0095)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.05	0.01	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	2	ND-0.004	0.002	Wallingford, CT	Urban	88	5	
	NR	NR	ND(0.02)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.03)	NA	Durham, NC	Urban	NR	6	
	1	1	0.0004	0.0004	Stockholm, Sweden	Urban	89	7	
	2	2	0.02-0.06	0.04	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.02-0.08	0.05	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	0	ND(.012-0.2)	NA	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(0.24-0.82)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.15)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(0.058)	NA	Waldo, OH	Rural	87	9	background site
	3	0	ND(0.04-0.15)	NA	Albany, NY	Urban	87-88	11	
	1	0	ND(0.06)	NA	Binghamton, NY	Urban	88	11	
	2	0	ND(0.05-0.18)	NA	Utica, NY	Urban	88	11	
	2	0	ND(0.04-0.21)	NA	Niagara Falls, NY	Industrial	87	11	
	1	1	0.0004	0.0004	Stockholm	Urban	89	12	
	1	1	0.0007	0.0007	Stockholm	Suburban	89	12	
	1	1	0.0002	0.0002	Stockholm	Rural	89	12	
	1	1	0.0001	0.0001	Stockholm	Coastal	89	12	
	7	0	ND(0.004-0.023)	NA	Reseda, CA	Urban	87-89	14	mostly residential

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
2,3,7,8-TCDD (continued)	1	0	ND(0.030)	NA	Commerce, CA	Urban	87	14	near freeway
	6	0	ND(0.0026-0.048)	NA	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	0	ND(0.0106-0.045)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.0070-0.051)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	1	ND-0.034	.017	Cal Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.022-0.039)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	1	ND-0.0086	0.0079	West Long Beach, CA	Urban	88-89	14	mostly residential area
TCDDs	16	3	ND-0.18	0.04	Niagra Falls, NY	Urban	86-87	1	
	16	12	ND-10.12	0.99	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-0.54	0.20	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	27	20	ND-0.07	0.03	Wallingford, CT	Urban	88	5	
	1	1	0.05	0.05	Stockholm, Sweden	Urban	89	7	
	2	2	0.10-0.22	0.16	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.21-1.5	0.86	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	1	ND-0.18	0.12	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(0.24-0.82)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.15)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(0.058)	NA	Waldo, OH	Rural	87	9	background Site
	3	0	ND(0.04-0.15)	NA	Albany, NY	Urban	87-88	11	
	1	0	ND(0.06)	NA	Binghamton, NY	Urban	88	11	
	2	0	ND(0.05-0.18)	NA	Utica, NY	Urban	88	11	
	2	0	ND(0.04-0.21)	NA	Niagara Falls, NY	Industrial	87	11	
	1	1	0.05	0.05	Stockholm	Urban	89	12	

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
TCDDs (continued)	1	1	0.026	0.026	Stockholm	Suburban	89	12	
	1	1	0.031	0.031	Stockholm	Rural	89	12	
	1	1	0.0057	0.0057	Stockholm	Coastal	89	12	
	7	0	ND(0.0050-0.046)	NA	Reseda, CA	Urban	87-89	14	mostly residential
	1	0	ND(0.030)	NA	Commerce, CA	Urban	87	14	near freeway
	6	0	ND(0.0026-0.075)	NA	North Long Beach,CA	Urban	87-89	14	mostly residential
	5	0	ND(0.0106-0.093)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.0090-0.051)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	1	ND-0.280	0.0788	Cak Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.0230	0.0170	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	1	ND-0.0402	0.0237	West Long Beach, CA	Urban	88-89	14	mostly residential
Pentachlorodibenzo-p-dioxins (MW=356.42)									
1,2,3,7,8-PeCDD	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	1	ND-0.49	0.17	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	ND(0.02)	NA	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.039)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.07	0.02	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	9	ND-0.02	0.006	Wallingford, CT	Urban	88	5	
	NR	NR	ND(0.03)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.01)	NA	Durham, NC	Urban	NR	6	
	1	1	0.006	0.006	Stockholm, Sweden	Urban	89	7	
	2	1	ND-0.28	0.14	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.22-0.60	0.41	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDD (continued)	3	0	ND(.034-0.27)	NA	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(.047-.06)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.082)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(0.033)	NA	Waldo, OH	Rural	87	9	background site
	1	1	0.006	0.006	Stockholm	Urban	89	12	
	1	1	0.0038	0.0038	Stockholm	Suburban	89	12	
	1	1	0.0014	0.0014	Stockholm	Rural	89	12	
	1	1	0.0007	0.0007	Stockholm	Coastal	89	12	
	1	1	0.0004	0.0004	Bloomington, IN	Urban	86	13	
	7	1	ND-0.14	0.0332	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.120	0.120	Commerce, CA	Urban	87	14	near freeway
	6	0	ND(0.0060-0.095)	NA	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	0	ND(0.048-0.93)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.0062-0.058)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.0126-0.081)	NA	Cal Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.0090-0.054)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.043-0.088)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
PeCDDs	16	1	ND-0.05	0.02	Niagra Falls, NY	Urban	86-87	1	
	16	11	ND-11.16	1.04	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	0.01-0.66	0.24	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	21	ND-0.15	0.05	Wallingford, CT	Urban	88	5	
	1	1	0.11	0.11	Stockholm, Sweden	Urban	89	7	

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
PeCDDs (continued)	2	2	0.07-1.3	0.68	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	2.4-5.0	3.70	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	1	ND-0.10	0.097	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(0.47-.06)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.082)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(0.033)	NA	Waldo, OH	Rural	87	9	background site
	3	0	ND(0.04-0.21)	NA	Albany, NY	Urban	87-88	11	
	1	0	ND(0.11)	NA	Binghamton, NY	Urban	88	11	
	2	0	ND(0.07-0.34)	NA	Utica, NY	Urban	88	11	
	2	0	ND(0.07-0.34)	NA	Niagara, NY	Industrial	87	11	
	1	1	0.110	0.110	Stockholm	Urban	89	12	
	1	1	0.079	0.079	Stockholm	Suburban	89	12	
	1	1	0.04	0.04	Stockholm	Rural	89	12	
	1	1	0.019	0.019	Stockholm	Coastal	89	12	
	7	2	ND-0.89	0.143	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.57	0.57	Commerce, CA	Urban	87	14	near freeway
	6	2	ND-0.81	0.150	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	0	ND(0.063-0.93)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.0062-0.047)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	1	ND-0.18	0.0618	Cal Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.042	0.0345	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.045-0.088)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
Hexachlorodibenzo-p-dioxins (MW = 390.87)									
1,2,3,4,7,8-HxCDD	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	3	.04-.64	0.24	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.01	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.076)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.08	0.03	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	8	ND-0.03	0.01	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.05	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.01	Durham, NC	Urban	NR	6	
	1	1	0.004	0.004	Stockholm, Sweden	Urban	89	7	
	2	0	ND(0.08-0.17)	NA	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.19-1.0	0.60	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	.032-.055	0.041	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(.028-.039)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.032)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.031	0.031	Waldo, OH	Rural	87	9	background site
	1	1	0.004	0.004	Stockholm	Urban	89	12	
	1	1	0.0028	0.0028	Stockholm	Suburban	89	12	
	1	1	0.0012	0.0012	Stockholm	Rural	89	12	
	1	1	0.0006	0.0006	Stockholm	Coastal	89	12	
	1	1	0.0023	0.0023	Bloomington, IN	Urban	86	13	
	7	3	ND-0.20	0.0588	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.12	0.12	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.14	0.0402	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-0.043	0.0406	San Bernadino, CA	Urban	87-89	14	mostly residential

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDD (continued)	7	0	ND(0.012-0.10)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.0078-0.074)	NA	Cal Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.015-0.025)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.038-0.043)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,6,7,8-HxCDD	3	1	ND-.03	0.02	Niagra Falls, NY	Urban	86-87	1	
	3	3	.05-1.06	0.39	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.02	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.083)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.13	0.04	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	22	ND-0.06	0.02	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.07	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.01	Durham, NC	Urban	NR	6	
	1	1	0.008	0.008	Stockholm, Sweden	Urban	89	7	
	2	2	0.23-0.66	0.44	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.71-2.2	1.46	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	.052-.053	0.053	Akron, OH	Industrial	87	9	near incinerators
	2	1	ND-0.078	0.046	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.032)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.025	0.025	Waldo, OH	Rural	87	9	background site
	1	1	0.0076	0.0076	Stockholm	Urban	89	12	
	1	1	0.0062	0.0062	Stockholm	Suburban	89	12	
	1	1	0.0023	0.0023	Stockholm	Rural	89	12	
	1	1	0.0009	0.0009	Stockholm	Coastal	89	12	

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDD (continued)	1	1	0.0029	0.0029	Bloomington, IN	Urban	86	13	
	7	3	ND-0.35	0.0801	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.25	0.25	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.39	0.0833	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-0.15	0.0586	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.0070-0.097)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	1	ND-0.065	0.0383	Cal Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.015-0.025)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.019-0.032)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,7,8,9-HxCDD	3	1	ND-.03	0.02	Niagra Falls, NY	Urban	86-87	1	
	3	2	ND-0.11	0.06	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.02	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.086)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.25	0.08	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	18	ND-0.07	0.03	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.05	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.01)	NA	Durham, NC	Urban	NR	6	
	1	0	ND(0.001)	NA	Stockholm, Sweden	Urban	89	7	
	2	0	ND(0.08-0.17)	NA	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.36-5.2	2.78	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	.017-.050	0.031	Akron, OH	Industrial	87	9	near incinerators
	2	1	ND-.064	0.039	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.032)	NA	Columbus, OH	Urban	87	9	next to interstate highway

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDD (continued)	1	1	0.025	0.025	Waldo, OH	Rural	87	9	background site
	1	1	0.0065	0.0065	Stockholm	Urban	89	12	
	1	1	0.0052	0.0052	Stockholm	Suburban	89	12	
	1	1	0.0018	0.0018	Stockholm	Rural	89	12	
	1	1	0.0013	0.0013	Stockholm	Coastal	89	12	
	1	1	0.0013	0.0013	Bloomington, IN	Urban	86	13	
	7	3	ND-0.35	0.1198	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.27	0.27	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.35	0.0758	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-0.10	0.0499	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.009-0.12)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.023-0.074)	NA	Cal Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.015-0.019)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.019-0.040)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
HxCDDs	16	11	ND-0.23	0.08	Niagra Falls, NY	Urban	86-87	1	
	16	12	ND-12.16	1.69	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-2.17	0.72	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	27	ND-0.68	0.26	Wallingford, CT	Urban	88	5	
	1	1	0.10	0.10	Stockholm, Sweden	Urban	89	7	
	2	2	0.74-2.7	1.72	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	5.3-24	14.6	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	0.6-0.63	0.62	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.43-0.78	0.60	Columbus, OH	Industrial	87	9	near incinerators

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HxCDDs (continued)	1	1	0.15	0.15	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.33	0.33	Waldo, OH	Rural	87	9	background site
	3	1	ND(0.34)-0.13	0.125	Albany, NY	Urban	NR	11	
	1	0	ND(0.16)	NA	Binghamton, NY	Urban	NR	11	
	2	1	ND(0.55)-0.1	0.188	Utica, NY	Urban	NR	11	
	2	1	ND(0.11)-0.17	0.112	Niagara Falls, NY	Industrial	NR	11	
	1	1	0.096	0.096	Stockholm	Urban	89	12	
	1	1	0.082	0.082	Stockholm	Suburban	89	12	
	1	1	0.03	0.03	Stockholm	Rural	89	12	
	1	1	0.014	0.014	Stockholm	Coastal	89	12	
	7	7	0.062-3.0	0.988	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	2.00	2.00	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-3.2	0.640	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	2	ND-0.77	0.197	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.11	0.0424	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-0.27	0.153	Cal Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.14	0.10	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.16-0.32	0.241	West Long Beach, CA	Urban	88-89	14	mostly residential
Heptachlorodibenzo-p-dioxins (MW = 425.31)									
1,2,3,4,6,7,8-HpCDD	3	3	0.34-0.51	0.41	Niagra Falls, NY	Urban	86-87	1	
	3	2	ND-5.43	2.0	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.11	Greenbay, WI	Urban	NR	2	
	1	1	0.25	0.25	Los Angeles, CA	Urban	87	3	
	7	NR	0.02-1.07	0.48	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	23	ND-0.73	0.29	Wallingford, CT	Urban	88	5	

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDD (continued)	NR	NR	NR	0.41	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.04	Durham, NC	Urban	NR	6	
	1	1	0.10	NA	Stockholm, Sweden	Urban	89	7	
	3	3	0.52-0.57	0.54	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.26-0.52	0.39	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.32	0.32	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.24	0.24	Waldo, OH	Rural	87	9	background site
	1	1	0.1	0.1	Stockholm	Urban	89	12	
	1	1	0.091	0.091	Stockholm	Suburban	89	12	
	1	1	0.027	0.027	Stockholm	Rural	89	12	
	1	1	0.012	0.012	Stockholm	Coastal	89	12	
	1	1	0.0051	0.0051	Bloomington, IN	Urban	86	13	
	7	7	0.11-8.40	2.44	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	2.70	2.70	Commerce, CA	Urban	87	14	near freeway
	6	6	0.21-3.50	0.795	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	5	0.21-1.20	0.582	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.26	0.138	El Toro, CA	Urban	87-88	14	mostly residential
	4	4	0.41-0.87	0.540	Cal. Transit, CA	Urban	88-89	14	near highway
	2	2	0.19-0.22	0.205	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.30-0.40	0.351	West Long Beach, CA	Urban	88-89	14	mostly residential
HpCDDs	16	14	ND-0.86	0.44	Niagra Falls, NY	Urban	86-87	1	
	15	15	0.24-9.78	2.60	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	0.02-2.19	1.02	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	26	ND-1.48	0.61	Wallingford, CT	Urban	88	5	
	1	1	0.20	0.20	Stockholm, Sweden	Urban	89	7	

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
HpCDDs (continued)	2	2	0.6-3.4	2.0	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	5.3-15	10.2	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	1.00-1.10	1.07	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.41-1.00	0.70	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.56	0.56	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.48	0.48	Waldo, OH	Rural	87	9	background site
	3	2	0.28-0.69	0.44	Albany, NY	Urban	NR	11	
	1	1	0.48	0.48	Binghamton, NY	Urban	NR	11	
	2	1	ND(0.77)-0.3	0.342	Utica, NY	Urban	NR	11	
	2	2	0.49-0.56	0.525	Niagara Falls, NY	Industrial	NR	11	
	1	1	0.2	0.2	Stockholm	Urban	89	12	
	1	1	0.19	0.19	Stockholm	Suburban	89	12	
	1	1	0.062	0.062	Stockholm	Rural	89	12	
	1	1	0.03	0.03	Stockholm	Coastal	89	12	
	7	7	0.24-8.90	4.94	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	5.30	5.30	Commerce, CA	Urban	87	14	near freeway
	6	6	0.24-7.20	1.61	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	5	0.43-1.60	1.06	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.46	0.246	El Toro, CA	Urban	87-88	14	mostly residential
	4	4	0.66-1.96	1.07	Cal. Transit, CA	Urban	88-89	14	near highway
	2	2	0.46-0.48	0.467	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.70-0.78	0.739	West Long Beach, CA	Urban	88-89	14	mostly residential
Octachlorodibenzo-p-dioxin (MW = 460.76)									
1,2,3,4,6,7,8,9-OCDD	16	15	ND-5.79	1.14	Niagra Falls, NY	Urban	86-87	1	
	14	14	0.39-8.88	2.94	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	NR	NR	NR	0.30	Greenbay, WI	Urban	NR	2	
	1	1	1.9	1.9	Los Angeles, CA	Urban	87	3	
	7	NR	0.17-5.55	2.10	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	16	15	ND-29.5	5.53	Wallingford, CT	Urban	88	5	
	NR	NR	NR	1.10	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.13	Durham, NC	Urban	NR	6	
	1	1	0.23	0.23	Stockholm, Sweden	Urban	89	7	
	2	2	0.37-6.4	3.38	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	7.4-40	23.7	Hamburg, Germany	Urban	NR	8	downwind incinerator & industrial complex
	3	3	1.00-1.20	1.13	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.51-1.10	0.80	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.96	0.96	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.50	0.50	Waldo, OH	Rural	87	9	background site
	1	1	0.053	0.053	Trout Lake, WI	Rural	NR	10	background site
	3	2	0.6-3.16	1.53	Albany, NY	Urban	NR	11	
	1	1	1.35	1.35	Binghamton, NY	Urban	NR	11	
	2	2	0.84-1.58	1.21	Utica, NY	Urban	NR	11	
	2	2	1.4-1.6	1.5	Niagara Falls, NY	Insdustrial	NR	11	
	1	1	0.23	0.23	Stockholm	Urban	89	12	
	1	1	0.23	0.23	Stockholm	Suburban	89	12	
	1	1	0.068	0.068	Stockholm	Rural	89	12	
	1	1	0.041	0.041	Stockholm	Coastal	89	12	
	6	6	0.43-17.0	5.36	Reseda, CA	Urban	87-89	14	mostly residential
	5	5	0.68-1.90	1.42	North Long Beach, CA	Urban	87-89	14	near freeway
	5	5	0.93-8.60	3.08	San Bernadino, CA	Urban	87-89	14	mostly residential

Table B-14. Environmental Levels of Dioxins in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDD (continued)	7	6	ND-2.16	1.05	El Toro, CA	Urban	87-88	14	mostly residential
	4	4	1.80-3.73	2.37	Cal. Transit, CA	Urban	88-89	14	near highway
	2	2	0.48-1.60	1.04	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	2.05-3.83	2.94	West Long Beach, CA	Urban	88-89	14	mostly residential

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = Not applicable;
ND = Non-detect;
NR = Not reported.

Sources:

1. Smith, et al. (1989).
2. Harless, et al. (1990).
3. Maisel and Hunt (1990).
4. Hunt and Maisel (1990).
5. CDEP (1988).
6. Harless and Lewis (1991).
7. Naf, et al. (1990).
8. Rappe and Kjeller (1987).
9. Edgerton, et al. (1989).
10. Eitzer and Hites (1989).
11. Smith, et al. (1990).
12. Broman, et al. (1991).
13. Eitzer and Hites (1989).
14. Hunt, et al. (1990).

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
Tetrachlorodibenzofurans (MW = 305.98)									
2,3,7,8-TCDF	3	3	0.04-0.14	0.09	Niagra Falls, NY	Urban	86-87	1	
	3	3	.28-3.81	1.47	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.03	Greenbay, WI	Urban	NR	2	
	1	1	0.02	0.02	Los Angeles, CA	Urban	87	3	
	7	NR	ND-.20	0.08	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	22	ND-0.10	0.04	Wallingford, CT	Urban	88	5	
	NR	NR	ND(0.1)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.03	Durham, NC	Urban	NR	6	
	2	2	0.04-0.72	0.38	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.18-0.38	0.28	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	0.19-0.20	0.20	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.32-0.49	0.40	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.13)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.13	0.13	Waldo, OH	Rural	87	9	background site
	3	3	0.5-1.24	0.85	Albany, NY	Urban	87-89	11	
	1	1	0.18	0.18	Binghamton, NY	Urban	88	11	
	2	2	1.07-1.23	1.15	Utica, NY	Urban	88	11	
	2	0	ND(0.04-0.2)	NA	Niagra Falls, NY	Industrial	87	11	
	7	4	ND-0.046	0.0271	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.11	0.11	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-0.039	0.0198	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	4	ND-0.091	0.0383	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	3	ND-0.027	0.0146	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-0.21	0.0687	Cal. Transit, CA	Urban	88-89	14	near highway

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
2,3,7,8,-TCDF (continued)	2	1	ND-0.024	0.0137	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.019-0.48	0.250	West Long Beach, CA	Urban	88-89	14	mostly residential
TCDFs	16	10	ND-0.66	0.23	Niagra Falls, NY	Urban	86-87	1	
	16	16	0.18-17.4	3.25	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-2.29	0.86	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	26	ND-0.86	0.38	Wallingford, CT	Urban	88	5	
	1	1	0.33	0.33	Stockholm, Sweden	Urban	89	7	
	2	2	0.36-6.2	3.28	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	3.3-4.9	4.1	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	0.99-1.50	1.23	Akron, OH	Industrial	87	9	near incinerators
	2	2	1.90-3.80	2.85	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.13)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.89	0.89	Waldo, OH	Rural	87	9	background site
	3	3	2.08-5.46	3.64	Albany, NY	Urban	87-88	11	
	1	1	0.94	0.94	Binghamton, NY	Urban	88	11	
	2	2	5.87-8.81	7.34	Utica, NY	Urban	88	11	
	2	2	1.10-1.20	1.15	Niagra Falls, NY	Industrial	87	11	
	1	1	0.33	0.33	Stockholm	Urban	89	12	
	1	1	0.20	0.20	Stockholm	Urban	89	12	
	1	1	0.08	0.08	Stockholm	Urban	89	12	
	1	1	0.048	0.048	Stockholm	Urban	89	12	
	7	5	ND-1.10	0.275	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	1.40	1.40	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-1.00	0.432	North Long Beach, CA	Urban	87-89	14	mostly residential

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m^3) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
TCDFs (continued)	5	5	0.024-0.98	0.430	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.32	0.147	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-0.87	0.418	Cal. Transit, CA	Urban	88-89	14	near freeway
	2	2	0.089-0.32	0.206	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.15-0.48	0.316	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,7,8-PeCDF (MW=340.42)									
1,2,3,7,8-PeCDF	3	0	ND(0.01)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	3	0.03-0.61	0.25	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.05	Greenbay, WI	Urban	NR	2	
	1	1	0.08	0.08	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.10	0.03	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	9	ND-0.02	0.01	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.03	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.01	Durham, NC	Urban	NR	6	
	3	3	.026-.033	0.029	Akron, OH	Industrial	87	9	near incinerators
	2	2	.032-.057	0.044	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.036)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.021	0.021	Waldo, OH	Rural	87	9	background site
	7	1	ND-0.14	0.0327	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.092	0.0920	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.13	0.0383	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-1.90	0.399	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	2	ND-0.077	0.0349	El Toro, CA	Urban	87-89	14	mostly residential
	4	1	ND-0.053	0.0346	Cal Transit, CA	Urban	88-89	14	near highway

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8-PeCDF	2	0	ND(0.010-0.015)	NA	Carson, CA	Industrial	88-89	14	On site at gas cooking equipment manufacturer
(continued)	2	1	ND-0.022	0.0161	West Long Beach, CA	Urban	88-89	14	mostly residential
2,3,4,7,8-PeCDF	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	2	ND-1.92	0.68	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.04	Greenbay, WI	Urban	NR	2	
	1	1	0.08	0.08	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.16	0.05	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	16	ND-0.04	0.02	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.20	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.01	Durham, NC	Urban	NR	6	
	1	1	0.02	0.02	Stockholm, Sweden	Urban	89	7	
	1	1	0.04	0.04	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.43-1.2	0.82	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	.032-.042	0.036	Akron, OH	Industrial	87	9	near incinerators
	2	1	ND-.089	0.050	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.036)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(0.033)	NA	Waldo, OH	Rural	87	9	background site
	1	1	0.018	0.018	Stockholm	Urban	89	12	
	1	1	0.0078	0.0078	Stockholm	Urban	89	12	
	1	1	0.0021	0.0021	Stockholm	Urban	89	12	
	1	1	0.0012	0.0012	Stockholm	Urban	89	12	
	7	1	ND-0.11	0.0295	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.0890	0.0890	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.13	0.0393	North Long Beach, CA	Urban	87-89	14	mostly residential

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
2,3,4,7,8-PeCDF (continued)	5	1	ND-0.10	0.0379	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	2	ND-0.08	0.0363	El Toro, CA	Urban	87-88	14	mostly residential
	4	1	ND-0.15	0.0516	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.010-0.012)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.010-0.012)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
PeCDFs	16	8	ND-0.41	0.12	Niagra Falls, NY	Urban	86-87	1	
	16	15	ND-12.4	2.08	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-1.77	0.57	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	28	0.04-0.71	0.29	Wallingford, CT	Urban	88	5	
	1	1	0.17	0.17	Stockholm, Sweden	Urban	89	7	
	2	2	0.51-4.1	2.30	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	5-10	7.5	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	0.53-0.66	0.59	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.69-1.30	1.00	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.036)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.50	0.50	Waldo, OH	Rural	87	9	background site
	3	3	1.24-3.26	1.96	Albany, NY	Urban	87-88	11	
	1	1	0.25	0.25	Binghamton, NY	Urban	88	11	
	2	2	2.71-3.61	3.16	Utica, NY	Urban	88	11	
	2	2	0.31-0.39	0.35	Niagra Falls, NY	Industrial	87	11	
	1	1	0.170	0.17	Stockholm	Urban	89	12	
	1	1	0.094	0.094	Stockholm	Urban	89	12	
	1	1	0.046	0.046	Stockholm	Urban	89	12	
	1	1	0.026	0.026	Stockholm	Urban	89	12	

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
PeCDFs (continued)	7	5	ND-1.90	0.402	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	1.00	1.00	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-1.50	0.450	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	2	ND-2.70	0.582	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.57	0.247	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-1.60	0.524	Cal. Transit, CA	Urban	88-89	14	near highway
	2	2	0.25-0.28	0.265	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.23-0.24	0.235	West Long Beach, CA	Urban	88-89	14	mostly residential
Hexachlorodibenzofurans (MW = 374.87)									
1,2,3,4,7,8-HxCDF	3	1	ND-0.06	0.02	Niagra Falls, NY	Urban	86-87	1	
	3	2	ND-0.22	0.11	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.03	Greenbay, WI	Urban	NR	2	
	1	1	0.15	0.15	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.41	0.11	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	21	ND-0.13	0.05	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.04	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.02	Durham, NC	Urban	NR	6	
	3	3	.053-0.10	0.083	Akron, OH	Industrial	87	9	near incinerators
	2	2	.060-0.27	0.16	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.034)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.098	0.098	Waldo, OH	Rural	87	9	background site
	7	1	ND-0.27	0.0586	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.180	0.180	Commerce, CA	Urban	87	14	near freeway

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8-HxCDF (continued)	6	1	ND-0.25	0.0574	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	2	ND-0.18	0.0821	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	2	ND-0.15	0.0499	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.039-0.15)	NA	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.038-0.054)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.029-0.085)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,6,7,8-HxCDF	3	1	ND-0.02	0.01	Niagra Falls, NY	Urban	86-87	1	
	3	3	0.05-1.17	0.45	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.03	Greenbay, WI	Urban	NR	2	
	1	1	0.25	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.15	0.04	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	17	ND-0.07	0.03	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.03	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.02	Durham, NC	Urban	NR	6	
	1	1	0.008	0.008	Stockholm, Sweden	Urban	89	7	
	2	2	0.03-0.15	0.09	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.24-1.4	0.82	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	.048-.092	0.065	Akron, OH	Industrial	87	9	near incinerators
	2	2	.092-0.19	0.14	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.034)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.014	0.014	Waldo, OH	Rural	87	9	background site
	1	1	0.0078	0.0078	Stockholm	Urban	89	12	
	1	1	0.0059	0.0059	Stockholm	Urban	89	12	

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,6,7,8-HxCDF (continued)	1	1	0.0024	0.0024	Stockholm	Urban	89	12	
	1	1	0.0014	0.0014	Stockholm	Urban	89	12	
	7	1	ND-0.80	0.130	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.41	0.410	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.48	0.0931	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-0.37	0.0977	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	2	ND-0.25	0.0689	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.031-0.092)	NA	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.030-0.036)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.060-0.070)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,7,8,9-HxCDF	3	0	ND(.01-.02)	NA	Niagra Falls, NY	Urban	86-87	1	
	3	1	ND-0.1	0.04	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.01	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.08)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.02	0.01	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	1	ND-0.003	0.003	Wallingford, CT	Urban	88	5	
	NR	NR	ND(0.03)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.01)	NA	Durham, NC	Urban	NR	6	
	1	1	0.0008	0.0008	Stockholm, Sweden	Urban	89	7	
	2	0	ND(.01-.05)	NA	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	1	ND-0.33	0.17	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	.020-.039	0.032	Akron, OH	Industrial	87	9	near incinerators
	2	2	.038-0.12	0.079	Columbus, OH	Industrial	87	9	near incinerators

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,7,8,9-HxCDF (continued)	1	0	ND(0.034)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.097	0.097	Waldo, OH	Rural	87	9	background site
	1	1	0.0008	0.0008	Stockholm	Urban	89	12	
	1	1	0.0006	0.0006	Stockholm	Urban	89	12	
	1	1	0.0003	0.0003	Stockholm	Urban	89	12	
	1	1	0.0004	0.0004	Stockholm	Urban	89	12	
	1	1	0.0001	0.0001	Bloomington, IN	Urban	86	13	
	7	0	ND(0.0040-0.075)	NA	Reseda, CA	Urban	87-89	14	mostly residential
	1	0	ND(0.11)	NA	Commerce, CA	Urban	87	14	near freeway
	6	0	ND(0.010-0.043)	NA	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	0	ND(0.033-0.21)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.015-0.083)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.0032-0.068)	NA	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.0054-0.014)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.040-0.086)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
2,3,4,6,7,8-HxCDF	3	1	ND-0.04	0.02	Niagra Falls, NY	Urban	86-87	1	
	3	2	ND-2.17	0.76	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	ND(.01)	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.08)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.30	0.09	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	19	ND-0.10	0.04	Wallingford, CT	Urban	88	5	

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
2,3,4,6,7,8-HxCDF (continued)	NR	NR	ND(0.03)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.01	NA	Durham, NC	Urban	NR	6	
	1	1	0.005	0.005	Stockholm, Sweden	Urban	89	7	
	2	1	ND-0.05	0.03	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.21-0.8	0.50	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	0	ND(.005-.036)	NA	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(.012-.028)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.034)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	0	ND(.008)	NA	Waldo, OH	Rural	87	9	background site
	1	1	0.0054	0.0054	Stockholm	Urban	89	12	
	1	1	0.0063	0.0063	Stockholm	Urban	89	12	
	1	1	0.002	0.002	Stockholm	Urban	89	12	
	1	1	0.0009	0.009	Stockholm	Urban	89	12	
	1	1	0.0016	0.0016	Bloomington, IN	Urban	86	13	
	7	1	ND-0.28	0.0551	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.180	0.180	Commerce, CA	Urban	87	14	near freeway
	6	1	ND-0.19	0.0474	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	1	ND-0.16	0.0584	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.018-0.078)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	0	ND(0.039-0.103)	NA	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.014-0.021)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.035-0.086)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
HxCDFs	16	11	ND-0.58	0.14	Niagra Falls, NY	Urban	86-87	1	
	16	15	ND-10.2	1.96	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-2.15	0.58	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	28	0.03-1.57	0.49	Wallingford, CT	Urban	88	5	
	1	1	0.08	0.08	Stockholm, Sweden	Urban	89	7	
	2	2	0.18-1.1	0.64	Hamburg, Germany	Urban	87-88	8	urban air & inside traffic tunnel
	2	2	2.2-9.5	5.85	Hamburg, Germany	Industrial	88	8	downwind incinerator & industrial complex
	3	3	0.56-0.70	0.62	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.37-1.20	0.78	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.10	0.10	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.51	0.51	Waldo, OH	Rural	87	9	background site
	3	3	0.19-0.37	0.31	Albany, NY	Urban	87-88	11	
	1	0	ND(0.09)	NA	Binghamton, NY	Urban	88	11	
	2	1	ND(0.26)-0.46	0.295	Utica, NY	Urban	88	11	
	2	2	0.12-0.18	0.15	Niagra Falls, NY	Industrial	87	11	
	1	1	0.078	0.078	Stockholm	Urban	89	12	
	1	1	0.062	0.062	Stockholm	Urban	89	12	
	1	1	0.029	0.029	Stockholm	Urban	89	12	
	1	1	0.015	0.015	Stockholm	Urban	89	12	
	7	5	ND-2.00	0.415	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	1.1	1.10	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-1.70	0.452	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	4	ND-0.90	0.606	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.40	0.162	El Toro, CA	Urban	87-88	14	mostly residential
	4	3	ND-0.84	.0341	Cal. Transit, CA	Urban	88-89	14	near highway

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
HxCDFs (continued)	2	2	0.19-0.27	.0230	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	1	ND-0.35	0.200	West Long Beach, CA	Urban	88-89	14	mostly residential
Heptachlorodibenzofurans (MW=409.31)									
1,2,3,4,6,7,8-HpCDF	3	1	ND-0.15	0.05	Niagra Falls, NY	Urban	86-87	1	
	3	3	0.26-5.43	2.08	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.08	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.2)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.54	0.21	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	22	ND-0.80	0.26	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.12	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.02	Durham, NC	Urban	NR	6	
	1	1	0.09	0.09	Stockholm, Sweden	Urban	89	7	
	3	3	0.22-0.25	0.24	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.20-0.47	0.34	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.087	0.087	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.22	0.22	Waldo, OH	Rural	87	9	background site
	1	1	0.087	0.087	Stockholm	Urban	89	12	
	1	1	0.055	0.055	Stockholm	Urban	89	12	
	1	1	0.028	0.028	Stockholm	Urban	89	12	
	1	1	0.011	0.011	Stockholm	Urban	89	12	
	1	1	0.0035	0.0035	Bloomington	Urban	86	13	
	7	3	ND-1.20	0.211	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.820	0.820	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-1.10	0.276	North Long Beach, CA	Urban	87-89	14	mostly residential

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8-HpCDF (continued)	5	3	ND-0.47	0.254	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	1	ND-0.13	0.0746	El Toro, CA	Urban	87-88	14	mostly residential
	4	3	ND-1.58	0.497	Cal. Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.20	0.110	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	1	ND-0.13	0.0733	West Long Beach, CA	Urban	88-89	14	mostly residential
1,2,3,4,7,8,9-HpCDF	NR	NR	NR	0.01	Greenbay, WI	Urban	NR	2	
	1	0	ND(0.02)	NA	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.07	0.03	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	12	ND-0.30	0.03	Wallingford, CT	Urban	88	5	
	NR	NR	ND(0.01)	NA	Rutland, VT	Urban	NR	6	
	NR	NR	ND(0.01)	NA	Durham, NC	Urban	NR	6	
	1	0	ND(0.001)	NA	Stockholm, Sweden	Urban	89	7	
	3	1	ND-0.031	0.020	Akron, OH	Industrial	87	9	near incinerators
	2	0	ND(.015-.028)	NA	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.013)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.019	0.019	Waldo, OH	Rural	87	9	background site
	1	1	0.004	0.004	Stockholm	Urban	89	12	
	1	1	0.0033	0.0033	Stockholm	Urban	89	12	
	1	1	0.0014	0.0014	Stockholm	Urban	89	12	
	1	1	0.0003	0.0003	Stockholm	Urban	89	12	
	1	1	0.0001	0.0001	Bloomington, IN	Urban	86	13	
	7	0	ND(0.0062-0.11)	NA	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	0.0920	0.0920	Commerce, CA	Urban	87	14	near freeway

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,4,7,8,9-HpCDF	6	1	ND-0.11	0.0397	North Long Beach, CA	Urban	87-89	14	mostly residential
(continued)	5	0	ND(0.030-0.12)	NA	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	0	ND(0.017-0.10)	NA	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-0.14	0.0606	Cal. Transit, CA	Urban	88-89	14	near highway
	2	0	ND(0.024-0.040)	NA	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	0	ND(0.015-0.043)	NA	West Long Beach, CA	Urban	88-89	14	mostly residential
HpCDFs	16	12	ND-0.43	0.13	Niagra Falls, NY	Urban	86-87	1	
	16	12	ND-8.76	1.67	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	7	NR	ND-1.0	0.37	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	26	ND-1.58	0.47	Wallingford, CT	Urban	88	5	
	1	1	0.11	0.11	Stockholm, Sweden	Urban	89	7	
	2	2	0.1-1.2	0.65	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	2-5	3.5	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	0.37-0.39	0.38	Akron, OH	Industrial	87	9	near incinerators
	2	2	0.26-0.64	0.45	Columbus, OH	Industrial	87	9	near incinerators
	1	1	0.15	0.15	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.29	0.29	Waldo, OH	Rural	87	9	background site
	3	1	ND-0.65	0.312	Albany, NY	Urban	87-88	11	
	1	0	ND(0.14)	NA	Binghamton, NY	Urban	88	11	
	2	1	ND(0.41)-0.07	0.138	Utica, NY	Urban	88	11	
	2	2	0.13-0.26	0.195	Niagra Falls, NY	Industrial	87	11	
	1	1	0.11	0.11	Stockholm	Urban	89	12	

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
HpCDFs (continued)	1	1	0.081	0.081	Stockholm	Urban	89	12	
	1	1	0.036	0.036	Stockholm	Urban	89	12	
	1	1	0.015	0.015	Stockholm	Urban	89	12	
	7	5	ND-1.40	0.288	Reseda, CA	Urban	87-89	14	mostly residential
	1	1	1.80	1.80	Commerce, CA	Urban	87	14	near freeway
	6	4	ND-1.20	0.327	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	3	ND-0.66	0.822	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	1	ND-0.13	0.0860	El Toro, CA	Urban	87-88	14	mostly residential
	4	3	ND-2.25	0.724	Cal. Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.33	0.174	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	1	ND-0.30	0.161	West Long Beach, CA	Urban	88-89	14	mostly residential
Octachlorodibenzofurans (MW = 444.76)									
1,2,3,4,6,7,8,9-OCDF	16	11	ND-0.22	0.09	Niagra Falls, NY	Urban	86-87	1	
	15	8	ND-3.38	0.62	Niagra Falls, NY	Industrial	86-87	1	downwind industrial complex
	NR	NR	NR	0.07	Greenbay, WI	Urban	NR	2	
	1	1	0.06	0.06	Los Angeles, CA	Urban	87	3	
	7	NR	ND-0.56	0.21	Bridgeport, CT	Urban	87-88	4	composite of 2-7 samples
	28	18	ND-0.70	0.21	Wallingford, CT	Urban	88	5	
	NR	NR	NR	0.14	Rutland, VT	Urban	NR	6	
	NR	NR	NR	0.03	Durham, NC	Urban	NR	6	
	1	1	0.02	0.02	Stockholm, Sweden	Urban	89	7	
	2	0	ND(0.11-1.0)	NA	Hamburg, Germany	Urban	NR	8	urban air & inside traffic tunnel
	2	2	0.78-7.0	3.89	Hamburg, Germany	Industrial	NR	8	downwind incinerator & industrial complex
	3	3	0.17-0.19	0.18	Akron, OH	Industrial	87	9	near incinerators

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m^3) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location range	Location description	Sample year	Ref. no.	Comments
1,2,3,4,6,7,8,9-OCDF (continued)	2	1	ND-0.21	0.18	Columbus, OH	Industrial	87	9	near incinerators
	1	0	ND(0.16)	NA	Columbus, OH	Urban	87	9	next to interstate highway
	1	1	0.077	0.077	Waldo, OH	Rural	87	9	background site
	3	1	ND(0.93)-0.3	0.312	Albany, NY	Urban	87-88	11	
	1	0	ND(0.3)	NA	Binghamton, NY	Urban	88	11	
	2	0	ND(0.12-1.10)	NA	Utica, NY	Urban	88	11	
	2	2	0.12-0.18	0.15	Niagra Falls, NY	Industrial	87	11	
	1	1	0.016	0.016	Stockholm	Urban	89	12	
	1	1	0.0072	0.0072	Stockholm	Urban	89	12	
	1	1	0.003	0.003	Stockholm	Urban	89	12	
	1	1	0.0009	0.0009	Stockholm	Urban	89	12	
	6	3	ND-0.13	0.116	Reseda, CA	Urban	87-89	14	mostly residential
	5	2	ND-0.43	0.152	North Long Beach, CA	Urban	87-89	14	mostly residential
	5	3	ND-0.29	0.162	San Bernadino, CA	Urban	87-89	14	mostly residential
	7	4	ND-0.13	0.0756	El Toro, CA	Urban	87-88	14	mostly residential
	4	2	ND-2.17	0.662	Cal. Transit, CA	Urban	88-89	14	near highway
	2	1	ND-0.12	0.164	Carson, CA	Industrial	88-89	14	on site at gas cooking equipment manufacturer
	2	2	0.32-0.43	0.374	West Long Beach, CA	Urban	88-89	14	mostly residential

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = Not available;
NR = Not reported;
ND = Non-detect.

Table B-15. Environmental Levels of Dibenzofurans in Air (pg/m³) (continued)

Sources:

1. Smith, et al. (1989).
2. Harless, et al. (1990).
3. Maisel and Hunt (1990).
4. Hunt and Maisel (1990).
5. CDEP (1988).
6. Harless and Lewis (1991).
7. Naf, et al. (1990).
8. Rappe and Kjeller (1987).
9. Edgerton, et al. (1989).
10. Eitzer and Hites (1989).
11. Smith, et al. (1990).
12. Broman, et al. (1991).
13. Eitzer and Hites (1989).
14. Hunt, et al. (1990).

Table B-16. Environmental Levels of PCBs in Air (pg/m^3)

IUPAC Number	Chemical	Number samples	Number positive samples	Concentration range	Conc. mean	Location	Location description	Sample year	Ref. no.	Comments
Pentachloro-PCB (MW=326.44)										
118	2,3',4,4',5-PeCB	143	143	NR	2.3	Egbert, ON	Rural	88-89	14	
114	2,3,4,4',5-PeCB	143	143	NR	1.2	Egbert, ON	Rural	88-89	14	
105	2,3,3',4,4'-PeCB	143	143	NR	0.16	Egbert, ON	Rural	88-89	14	
Hexachloro-PCB (MW=360.88)										
156	2,3,3',4,4',5-HxCB	143	143	NR	0.07	Egbert, ON	Rural	88-89	14	
Heptachloro-PCB (MW=396.33)										
189	2,3,3',4,4',5,5'-HpCB	143	143	NR	0.01	Egbert, ON	Rural	88-89	14	

Footnote References

NOTES: Summary statistics provided in or derived from references; when reference did not compute mean, it was computed using one-half the detection limit for non-detects;
NA = not available;
NR = not reported;
ND = Non-detect.

Sources:

14. Hoff, et al. (1992).

Table B-17. Mean Background Environmental Levels of Dioxins in Soil (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no.
Tetrachlorodibenzo-p-dioxins (MW=321.98)							
2,3,7,8-TCDD	135	19	ND-7	0.71	0.46	World Wide	1,6,7,10,11
	43	7	ND-5	0.88	0.81	North America	1,6
	92	12	ND-7	0.62	0.36	Europe	7,10,11
TCDDs	155	13	ND-120	17.4	12.4	World Wide	1,4,6,7,10,11
	65	0	ND(1.0-55)	22.6	14.2	North America	1,4,6
	90	13	ND-120	13.6	11.3	Europe	7,10,11
Pentachlorodibenzo-p-dioxins (MW=356.42)							
1,2,3,7,8-PeCDD	81	0,NR	ND-2.4	0.33	0.28	World Wide	6,11
	4	0	ND(3.75)	1.88	1.88	North America	6
	77	NR	ND-2.4	0.25	0.25	Europe	11
PeCDDs	161	20	ND-49.9	15.86	10.97	World Wide	1,4,6,7,10,11,14
	65	1	ND-27.5	23.10	15.78	North America	1,4,6
	96	19	ND-49.9	10.96	8.57	Europe	7,10,11,14
Hexachlorodibenzo-p-dioxins (MW=390.87)							
1,2,3,4,7,8-HxCDD	4	0	ND(3.75)	1.88	1.88	World Wide	6
	4	0	ND(3.75)	1.88	1.88	North America	6
	NA	NA	NA	NA	NA	Europe	NA
1,2,3,6,7,8-HxCDD	4	1	ND-14	4	4	World Wide	6
	4	1	ND-14	4	4	North America	6
	NA	NA	NA	NA	NA	Europe	NA
1,2,3,7,8,9-HxCDD	4	2	ND-9.9	9	9	World Wide	6
	4	2	ND-9.9	9	9	North America	6
	NA	NA	NA	NA	NA	Europe	NA
HxCDDs	155	18	ND-165	31.8	28.9	World Wide	1,4,6,7,10,11
	65	5	ND-99	26.5	22.5	North America	1,4,6
	90	13	ND-165	35.6	34.7	Europe	7,10,11

Table B-17. Mean Background Environmental Levels of Dioxins in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no.
Heptachlorodibenzo-p-dioxins (MW=425.31)							
1,2,3,4,6,7,8-HpCDD	4	4	37-360	194	194	World Wide	6
	4	4	37-360	194	194	North America	6
	NA	NA	NA	NA	NA	Europe	NA
HpCDDs	187	28	ND-640	51.4	34.9	World Wide	1,4,6,7,10,11,13
	95	15	ND-640	39.2	20.1	North America	1,4,6,13
	92	13	ND-234	63.9	61.6	Europe	7,10,11
Octachlorodibenzo-p-dioxin (MW=460.76)							
OCDD	185	42	ND-10,600	205	96.1	World Wide	1,4,6,7,10,11,13
	95	29	ND-10,600	237	59.9	North America	1,4,6,13
	90	13	ND-832	171	158	Europe	7,10,11
TEQs for Dibenzodioxins				4.51		World Wide	
				5.49		North America	
				0.92		Europe	

Table B-17. Mean Background Environmental Levels of Dioxins in Soil (ppt) (continued)

Footnote References

[a] Means were taken from pristine, reference, residential, rural, and agricultural sites. Industrial, urban, and dump sites were not used because they were assumed to be contaminated.

[b] Worldwide includes Europe and North America only.

NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)
NA = not applicable, no data found

Sources:

1. EPA (1985)
4. Pearson, et al. (1990).
6. Reed, et al. (1990).
7. Stenhouse and Badsha (1990).
10. Rappe and Kjeller (1987).
11. Creaser, et al. (1989).
13. Birmingham (1990).

Table B-18. Mean Background Environmental Levels of Dibenzofurans in Soil (ppt)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
Tetrachlorodibenzofurans (MW=305.98)							
2,3,7,8-TCDF	24	14	ND-50	9.29	4.85	World Wide	1,6,7
	12	2	ND-6	1.59	1.39	North America	1,6
	12	12	3-50	17	17	Europe	7
TCDFs	150	17	ND-300	42.2	33.8	World Wide	1,4,6,7,10,11
	58	2	ND-280	54.2	43.0	North America	1,4,6
	92	15	ND-300	34.5	29.1	Europe	7,10,11
Pentachlorodibenzofurans (MW=340.42)							
1,2,3,7,8-PeCDF	16	12	ND-10	3.47	3.31	World Wide	6,7
	4	0	ND(3.75)	1.88	1.88	North America	6
	12	12	1-10	4	4	Europe	7
2,3,4,7,8-PeCDF	16	12	ND-5	1.97	1.97	World Wide	6,7
	4	0	ND(3.75)	1.88	1.88	North America	6
	12	12	1-5	2	2	Europe	7
PeCDFs	160	24	ND-46.5	25.35	22.67	World Wide	1,4,6,7,10,11
	62	3	ND-27.5	25.81	20.22	North America	1,4,6
	98	21	ND-46.5	25.06	24.37	Europe	7,10,11
Hexachlorodibenzofurans (MW=374.87)							
1,2,3,4,7,8-HxCDF	4	0	ND(3.75)	1.88	1.88	World Wide	6
	4	0	ND(3.75)	1.88	1.88	North America	6
1,2,3,6,7,8-HxCDF	4	0	ND(3.75)	1.88	1.88	World Wide	6
	4	0	ND(3.75)	1.88	1.88	North America	6
	NA	NA	NA	NA	NA	Europe	NA
1,2,3,7,8,9-HxCDF	4	0	ND(3.75)	1.88	1.88	World Wide	6
	4	0	ND(3.75)	1.88	1.88	North America	6
	NA	NA	NA	NA	NA	Europe	NA
2,3,4,6,7,8-HxCDF	4	1	ND-7.1	2	2	World Wide	6
	4	1	ND-7.1	2	2	North America	6
HxCDF	157	19	ND-212	33.2	27.2	World Wide	1,4,6,7,10,11

Table B-18. Mean Background Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
HxCDF (cont.)	65	4	ND-150	26.5	17.7	North America	1,4,6
	92	15	ND-212	37.9	36.8	Europe	7,10,11
Heptachlorodibenzofurans (MW=409.31)							
1,2,3,4,6,7,8-HpCDF	4	4	11-80	47	47	World Wide	6
	4	4	11-80	47	47	North America	6
	NA	NA	NA	NA	NA	Europe	NA
1,2,3,4,7,8,9-HpCDF	4	0	ND(3.75)	1.88	1.88	World Wide	6
	4	0	ND(3.75)	1.88	1.88	North America	6
	NA	NA	NA	NA	NA	Europe	NA
HpCDFs	157	20	ND-260	110	52.1	World Wide	1,4,6,7,10,11
	65	5	ND-260	231	148.5	North America	1,4,6
	92	15	ND-138	25.0	24.8	Europe	7,10,11
Octachlorodibenzofurans (MW=444.76)							
OCDFs	155	17	ND-270	28.4	25.2	World Wide	1,4,6,7,10,11
	65	4	ND-270	30.2	23.1	North America	1,4,6
	90	13	ND-144	27.2	26.9	Europe	7,10,11
TEQs for Dibenzofurans				3.37		World Wide	
				2.48		North America	
				2.93		Europe	

Table B-18. Mean Background Environmental Levels of Dibenzofurans in Soil (ppt) (continued)

Footnote References

[a] Means were taken from pristine, reference, residential, rural, and agricultural sites. Industrial, urban, and dump sites were not used because they were assumed to be contaminated.

[b] Worldwide includes Europe and North America only.

NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)
NA = non-applicable, no data found
Sources:

1. EPA (1985)
4. Pearson, et al. (1990).
6. Reed, et al. (1990).
7. Stenhouse and Badsha (1990).
10. Rappe and Kjeller (1987)
11. Creaser, et al. (1989).

Table B-19. Mean Background Levels of Dioxins and Dibenzofurans in Water (ppq)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location	Ref. no(s).
Octachlorodibenzo-p-dioxin (MW=460.76)							
1,2,3,4,6,7,8,9-OCDD	214	4	ND-46	3.16	2.70	World Wide	1
	214	4	ND-46	3.16	2.70	North America	1
Octachlorodibenzofurans (MW=444.76)							
1,2,3,4,6,7,8,9-OCDF	22	2	ND-0.8	2.45	2.24	World Wide	2
	22	2	ND-0.8	2.45	2.24	North America	2
TEQs for Dibenzodioxins				0.0032		World Wide	
				0.0032		North America	
TEQs for Dibenzofurans				0.0025		World Wide	
				0.0025		North America	

Footnote References

[a] Means were taken from treated surface drinking water sample sites.

NOTES: One-half the limit of detection was used in calculating the means where applicable. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).
ND = non-detected (limit of detection)

Sources: 1. Jobb, et al. (1990)
2. Meyer, et al. (1989)

Table B-20. Mean Background Environmental Levels of Dioxins in Sediments (ppt)

Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a] (ppt)	Geometric mean[a] (ppt)	Location	Ref. no(s).
Tetrachlorodibenzo-p-dioxins (MW=321.98)							
2,3,7,8-TCDD	25	2	ND-35	25.9	16.2	World Wide	1,4,5,13
	5	0	ND(4.7-12.7)	3.16	2.88	North America	4,5
	20	2	ND-35	31.6	25.0	Europe	1,13
TCDDs	27	18	ND-1400	252	87.4	World Wide	1,3,5,13
	7	2	ND-26	6.81	2.95	North America	3,5
	20	16	ND-1400	338	286	Europe	1,13
Pentachlorodibenzo-p-dioxins (MW=356.42)							
PeCDDs	9	4	ND-100	20.5	5.52	World Wide	3,5,13
	7	2	ND-12	4.66	2.61	North America	3,5
	2	2	52-100	76	76	Europe	13
Hexachlorodibenzo-p-dioxins (MW=390.87)							
HxCDDs	9	6	ND-170	36.6	8.56	World Wide	3,5,13
	7	4	ND-14	5.57	3.81	North America	3,5
	2	2	120-170	145	145	Europe	13
Heptachlorodibenzo-p-dioxins (MW=425.31)							
HpCDDs	6	6	7.3-210	95.7	90.1	World Wide	5,13
	4	4	7.3-110	71	71	North America	5
	2	2	79-210	145	145	Europe	13

Table B-20. Mean Background Environmental Levels of Dioxins in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a] (ppt)	Geometric mean[a] (ppt)	Location	Ref. no(s).
Octachlorodibenzo-p-dioxin (MW=460.76)							
OCDD	27	12	ND-600	131	22.5	World Wide	1,3,5,13
	7	7	54-600	439	364	North America	3,5
	20	5	ND-250	22.5	8.51	Europe	1,13
TEQs for Dibenzodioxins				26.0		World Wide	
				3.60		North America	
				31.6		Europe	

Footnote References

[a] Means were taken from pristine, reference, residential, rural, and various location sites. Industrial, urban, and dump sites were not used because they were assumed to be contaminated.

NOTES: One-half the limit of detection was used in calculating the means where applicable.

ND = non-detected (limit of detection)
ppt = Parts per trillion

Sources:

1. Koistinen et al. (1990)
3. Czuczwa et al. (1984)
4. Norwood et al. (1989)
5. Reed et al. (1990)
13. Rappe et al. (1989a)

Table B-21. Mean Background Environmental Levels of Dibenzofurans in Sediments (ppt)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location	Ref. no(s).
Tetrachlorodibenzofurans (MW=305.98)							
2,3,7,8-TCDF	25	4	ND-35	26.7	11.7	World Wide	1,4,5,13
	5	2	ND-15	3.06	0.23	North America	4,5
	20	2	ND-35	32.6	31.2	Europe	1,13
TCDFs	9	6	ND-130	28.0	2.16	World Wide	3,5,13
	7	4	ND-18	4.86	0.7	North America	3,5
	2	2	87-130	109	109	Europe	13
Pentachlorodibenzofurans (MW=340.42)							
PeCDFs	9	6	ND-125	25.4	7.25	World Wide	3,5,13
	7	4	ND-25	5.26	3.26	North America	3,5
	2	2	66-125	96	96	Europe	13
Hexachlorodibenzofurans (MW=374.87)							
HxCDFs	9	5	ND-150	27.1	4.55	World Wide	3,5,13
	7	3	ND-12	2.31	1.81	North America	3,5
	2	2	78-150	114	114	Europe	13
Heptachlorodibenzofurans (MW=409.31)							
HpCDFs	6	5	ND-180	54.0	32.2	World Wide	5,13
	4	3	ND-30	16	16	North America	5
	2	2	79-180	130	130	Europe	13

Table B-21. Mean Background Environmental Levels of Dibenzofurans in Sediments (ppt) (continued)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location	Ref. no(s).
Octachlorodibenzofurans (MW=444.76)							
OCDF	27	8	ND-160	10.6	8.72	World Wide	1,3,5,13
	7	4	ND-23	4.50	3.98	North America	3,5
	20	4	ND-160	12.8	11.5	Europe	1,13
TEQs for Dibenzofurans				2.68		World Wide	
				0.31		North America	
				3.27		Europe	

Footnote References

[a] Means were taken from pristine, reference, residential, rural, and various location sites. Industrial, urban, and dump sites were not used because they were assumed to be contaminated.

NOTES: One-half the limit of detection was used in calculating the means where applicable.

ND = non-detected (limit of detection)
ppt = Parts per trillion

Sources:

1. Koistinen et al. (1990)
3. Czuczwa et al. (1984)
4. Norwood et al. (1989)
5. Reed et al. (1990)
13. Rappe et al. (1989a)

Table B-22. Mean Background Environmental Levels of PCBs in Sediment (ppt)

IUPAC number	Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a]	Geometric mean[a]	Location	Ref. no(s).
Tetrachloro-PCB (MW=291.99)								
77	3,3'4,4'-TeCB	19	13	ND-550	143.61	142	World Wide	1,16
		NR	NR	ND(500)	250	250	North America	16
		18	13	ND-550	137.7	137.7	Europe	1
81	3,4,4'5-TeCB	NR	NR	ND(500)	250	250	World Wide	16
		NR	NR	ND(500)	250	250	North America	16
Pentachloro-PCB (MW=326.44)								
126	3,3',4,4',5-PeCB	19	1	ND-110	13.26	7.42	World Wide	1,16
		NR	NR	ND(500)	250	250	North America	16
		18	1	ND-110	6.1	6.1	Europe	1
105	2,3,3',4,4'-PeCB	49	10	ND-10,000	7893.14	3834.95	World Wide	1,7,16
		39	NR	NR	9892.31	9861.3	North America	7,16
		10	10	52-120	96.4	96.4	Europe	1
114	2,3,4,4',5-PeCB	NR	NR	NR	1000	1000	World Wide	16
		NR	NR	NR	1000	1000	North America	16
118	2,3,4,4',5-PeCB			0.01-15,000	14,1897.44	14,881.18	World Wide	7,16,17
		38	NR	11,000-15,000	14,897.44	14,881.18	North America	7,16
		1	0	0.01	0.01	0.01	Europe	7,16,17
Hexachloro-PCB (MW=360.88)								
156	2,3,3',4,4',5-HxCB			1700-2100	2089.7	2088.7	World Wide	7,16
		38	NR	1700-2100	2089.7	2088.7	North America	7,16

Table B-22. Mean Background Environmental Levels of PCBs in Sediments (ppt) (continued)

IUPAC number	Chemical	Number samples	Number positive samples	Concentration range	Arithmetic mean[a]	Geometric mean[a]	Location	Ref. no(s).
167	2,3',4,4',5,5'-HxCB	NR	NR	ND(500)	250	250	World Wide	16
		NR	NR	ND(500)	250	250	North America	16
169	3,3',4,4',5,5'-HxCB	18	0	ND(36-500)	30.21	20.67	World Wide	1,16
		NR	NR	ND(500)	250	250	North America	16
		18	0	ND(36)	18	18	Europe	1
Heptachloro-PCB (MW=396.33)								
189	2,3,3',4,4',5,5'-HpCB	NR	NR	ND(500)	250	250	World Wide	16
		NR	NR	ND(500)	250	250	Europe	16

Footnote References

[a] Means were taken from various location sites. Industrial and urban sites were not used because they were assumed to be contaminated.

NOTES: One-half the limit of detection was used in calculating the means where applicable.

NR = Not Reported
ND = Not Detected (detection limit)
ppt = Parts per trillion

Sources:

1. Koistinen et al. (1990)
7. Oliver and Nilmi (1988)
9. Huckins et al. (1988)
16. Smith et al. (1990)

Table B-23. Mean Background Environmental Levels of Dioxins in Finfish (ppt)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
Tetrachlorodibenzo-p-dioxins (MW=321.98)							
2,3,7,8-TCDD	61	14	ND-2.26	0.343	0.263	World Wide	5,20
	60	14	ND-2.26	0.348	0.273	North America	20
	1	0	ND(0.05)	0.025	0.025	Europe	5
Pentachlorodibenzo-p-dioxins (MW=356.42)							
1,2,3,7,8-PeCDD	61	5	ND-0.3	0.411	0.369	World Wide	5,20
	60	4	ND-0.29	0.413	0.370	North America	20
	1	1	0.3	0.3	0.3	Europe	5
Hexachlorodibenzo-p-dioxins (MW=390.87)							
1,2,3,4,7,8-HxCDD	59	3	ND-0.35	0.566	0.509	World Wide	5,20
	60	3	ND-0.35	0.575	0.529	North America	20
	1	0	ND(0.1)	0.05	0.05	Europe	5
1,2,3,6,7,8-HxCDD	61	11	ND-1.79	0.597	0.536	World Wide	5,20
	60	11	ND-1.79	0.606	0.558	North America	20
	1	0	ND(0.1)	0.05	0.05	Europe	5
1,2,3,7,8,9-HxCDD	61	1	ND-0.17	0.478	0.441	World Wide	5,20
	60	1	ND-0.17	0.485	0.457	North America	20
	1	0	ND(0.1)	0.05	0.05	Europe	5

Table B-23. Mean Background Environmental Levels of Dioxins in Finfish (ppt) (continued)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
Heptachlorodibenzo-p-dioxins (MW=425.31)							
1,2,3,4,6,7,8-HpCDD	59	27	ND-4.08	1.547	1.122	World Wide	5,20
	58	27	ND-4.08	1.573	1.184	North America	20
	1	0	ND(0.1)	0.05	0.05	Europe	5
Octachlorodibenzo-p-dioxin (MW=460.76)							
1,2,3,4,6,7,8,9-OCDD	1	1	0.55	0.55	0.55	World Wide	5
	1	1	0.55	0.55	0.55	Europe	5
TEQs for Dibenzodioxins				0.729		World Wide	
				0.737		North America	
				0.191		Europe	

Footnote References

[a] Whole fish concentrations were divided in half to obtain the mean concentrations (USEPA, 1990; Branson et al., 1985).
[b] Worldwide includes North America and Europe only.
NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection);

Sources: 5. Rappe, et al. (1989)
20. USEPA (1992)

Table B-24. Mean Background Environmental Levels of Dibenzofurans in Finfish (ppt)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
Tetrachlorodibenzofurans (MW=305.98)							
2,3,7,8-TCDF	61	33	0.1-13.73	0.734	0.425	World Wide	5,20
	60	22	ND-6.87	0.732	0.420	North America	20
	1	1	0.85	0.85	0.85	Europe	5
Pentachlorodibenzofurans (MW=340.42)							
1,2,3,7,8-PeCDF	61	9	ND-0.95	0.253	0.219	World Wide	5,20
	60	8	ND-0.95	0.254	0.220	North America	20
	1	1	0.2	0.2	0.2	Europe	5
2,3,4,7,8-PeCDF	61	16	ND-1.5	0.286	0.245	World Wide	5,20
	60	15	ND-0.7	0.266	0.237	North America	20
	1	1	1.5	1.5	1.5	Europe	5
Hexachlorodibenzofurans (MW=374.87)							
1,2,3,4,7,8-HxCDF	61	4	ND-0.62	0.534	0.446	World Wide	5,20
	60	3	ND-0.62	0.541	0.458	North America	20
	1	1	0.1	0.1	0.1	Europe	5
1,2,3,6,7,8-HxCDF	61	2	ND-0.068	0.528	0.434	World Wide	5,20
	60	1	ND-0.68	0.536	0.450	North America	20
	1	1	0.05	0.05	0.05	Europe	5
1,2,3,7,8,9-HxCDF	60	0	ND(0.13-2.78)	0.534	0.443	World Wide	20
	60	0	ND(0.13-2.78)	0.534	0.443	North America	20

Table B-24. Mean Background Environmental Levels of Dibenzofurans in Finfish (ppt) (continued)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric mean[a]	Location[b]	Ref. no(s).
2,3,4,6,7,8-HxCDF	61	2	ND-0.63	0.402	0.347	World Wide	5,20
	60	2	ND-0.63	0.408	0.359	North America	20
	1	0	ND(0.2)	0.05	0.05	Europe	5
Heptachlorodibenzofurans (MW=409.31)							
1,2,3,4,6,7,8-HpCDF	59	8	ND-0.94	0.568	0.481	World Wide	5,20
	58	8	ND-0.94	0.577	0.500	North America	20
	1	0	ND(0.2)	0.05	0.05	Europe	5
Octachlorodibenzofurans (MW=444.76)							
1,2,3,4,6,7,8,9-OCDF	1	0	ND(0.2)		0.05	World Wide	5
	1	0	ND(0.2)	0.05	0.05	Europe	5
TEQs for Dibenzofurans				0.435		World Wide	
				0.427		North America	
				0.866		Europe	

Footnote References

[a] Whole fish concentrations were divided in half to obtain the mean concentrations (USEPA, 1990; Branson et al., 1985).
[b] Worldwide includes North America and Europe only.
NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)

Sources: 5. Rappe, et al. (1989)
20. USEPA (1992)

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
Tetrachlorodibenzo-p-dioxins (MW=321.98)								
2,3,7,8-TCDD	Milk	21	2	ND-0.063	0.010	0.009	World Wide	2,3,4,5,7
	Milk	1	1	0.0018	0.0018	0.0018	North America	4
	Milk	20	1	ND-0.063	0.011	0.010	Europe	2,3,5,7
	Dairy products	25	3	ND-0.26	0.103	0.072	World Wide	3,5,8,10
	Dairy products	5	2	ND-0.07	0.031	0.018	North America	10
	Dairy products	20	1	ND-0.26	0.121	0.102	Europe	3,5,8
	Eggs	9	1	ND-0.02	0.011	0.011	World Wide	3,11
	Eggs	8	0	ND(0.01-0.03)	0.01	0.01	North America	11
	Eggs	1	1	0.02	0.02	0.02	Europe	3
	Beef and veal	22	6	ND-0.062	0.027	0.022	World Wide	4,5,8,11,12
	Beef and veal	14	6	ND-0.062	0.026	0.021	North America	4,11,12
	Beef and veal	8	0	ND(0.015-0.05)	0.029	0.025	Europe	5,8
	Pork	16	2	ND-0.03	0.048	0.017	World Wide	4,3,5,11,12
	Pork	12	1	ND-0.013	0.018	0.010	North America	4,11,12
	Pork	4	1	ND-0.03	0.195	0.147	Europe	3,5
	Chicken	12	5	ND-0.25	0.05	0.032	World Wide	3,5,11,12
	Chicken	9	4	ND-0.25	0.055	0.030	North America	11,12
	Chicken	3	1	ND-0.045	0.040	0.040	Europe	3,5

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
Pentachlorodibenzo-p-dioxins (MW = 326.44)								
1,2,3,7,8-PeCDD	Milk	20	8	ND-0.082	0.029	0.027	World Wide	2,3,5,7
	Milk	20	8	ND-0.082	0.029	0.027	Europe	2,3,5,7
	Dairy products	25	6	ND-0.33	0.166	0.133	World Wide	3,5,8,10
	Dairy products	5	5	0.01-0.2	0.11	0.078	North America	10
	Dairy products	20	1	ND-0.33	0.18	0.15	Europe	3,5,8
	Eggs	9	1	ND-0.04	0.077	0.061	World Wide	3,11
	Eggs	8	0	ND(0.04-0.4)	0.081	0.065	North America	11
	Eggs	1	1	0.04	0.04	0.04	Europe	3
	Beef and veal	19	10	ND-0.87	0.224	0.111	World Wide	5,8,11,12
	Beef and veal	11	3	ND-0.208	0.221	0.082	North America	11,12
	Beef and veal	8	7	ND-0.87	0.23	0.17	Europe	5,8
	Pork	13	2	ND-0.018	0.119	0.087	World Wide	3,5,11,12
	Pork	9	1	ND-0.041	0.158	0.138	North America	11,12
	Pork	4	1	ND(0.075)-0.018	0.033	0.032	Europe	3,5
	Chicken	12	3	ND-0.18	0.117	0.062	World Wide	3,5,11,12
	Chicken	9	0	ND(0.011-1.11)	0.111	0.048	North America	11,12
	Chicken	3	3	0.105-0.18	0.14	0.13	Europe	3,5
Hexachlorodibenzo-p-dioxins (MW = 390.87)								
1,2,3,4,7,8-HxCDD	Milk	13	2	ND-0.66	0.028	0.027	World Wide	2,3,5

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
1,2,3,4,7,8-HxCDD (continued)	Milk	13	2	ND-0.66	0.028	0.027	Europe	2,3,5
	Dairy products	25	17	ND-0.29	0.117	0.093	World Wide	3,5,8,10
	Dairy products	5	5	0.017-0.29	0.107	0.063	North America	10
	Dairy products	20	12	ND-0.20	0.119	0.103	Europe	3,5,8
	Eggs	9	1	ND-0.13	0.15	0.14	World Wide	3,11
	Eggs	8	0	ND(0.08-0.67)	0.16	0.14	North America	11
	Eggs	1	1	0.13	0.13	0.13	Europe	3
	Beef and veal	8	7	ND-1.981	0.374	0.172	World Wide	5,8,12
	Beef	3	3	0.03-1.981	0.836	0.309	North America	12
	Beef and veal	8	7	ND-0.87	0.20	0.14	Europe	5,8
	Pork	4	1	0.032-0.282	0.086	0.0282	World Wide	3,5,12
	Pork	1	1	0.282	0.282	0.282	North America	12
	Pork	4	1	0.032-0.038	0.037	0.036	Europe	3,5
	Chicken	3	2	ND-0.12	0.044	0.070	World Wide	3,5,12
	Chicken	1	0	ND(0.04)	0.04	0.040	North America	12
	Chicken	3	2	ND-0.12	0.085	0.085	Europe	3,5
1,2,3,6,7,8-HxCDD	Milk	13	12	ND-0.33	0.11	0.10	World Wide	2,3,5
	Milk	13	12	ND-0.33	0.11	0.10	Europe	2,3,5
	Dairy products	25	20	ND-1.72	0.418	0.327	World Wide	3,5,8,10
	Dairy products	5	5	0.07-1.72	0.690	0.451	North America	10

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
1,2,3,6,7,8-HxCDD (continued)	Dairy products	20	15	ND-0.81	0.350	0.302	Europe	3,5,8
	Eggs	9	1	ND-0.14	0.13	0.12	World Wide	3,11
	Eggs	8	0	ND(0.07-0.56)	0.13	0.12	North America	11
	Eggs	1	1	0.14	0.14	0.14	Europe	3
	Beef and veal	16	8	ND-1.14	0.337	0.254	World Wide	5,8,11
	Beef and veal	8	0	ND(0.14-0.78)	0.263	0.214	North America	11
	Beef and veal	8	8	0.018-1.14	0.41	0.30	Europe	5,8
	Pork	12	1	ND-0.044	0.136	0.086	World Wide	3,5,11
	Pork	8	0	ND(0.096-0.54)	0.184	0.127	North America	11
	Pork	4	1	ND-0.044	0.040	0.039	Europe	3,5
	Chicken	11	5	ND-0.42	0.170	0.120	World Wide	3,5,11,12
	Chicken	9	2	ND-0.64	0.121	0.087	North America	11,12
	Chicken	3	3	0.26-0.42	0.32	0.31	Europe	3,5
1,2,3,7,8,9-HxCDD	Milk	20	2	ND-0.099	0.022	0.019	World Wide	2,3,5,7
	Milk	20	2	ND-0.099	0.022	0.019	Europe	2,3,5,7
	Dairy products	25	17	ND-0.29	0.154	0.131	World Wide	3,5,8,10
	Dairy products	5	5	0.02-0.29	0.156	0.117	North America	10
	Dairy products	20	12	ND-0.21	0.154	0.134	Europe	3,5,8
	Eggs	1	1	0.05	0.05	0.05	World Wide	3
	Eggs	1	1	0.05	0.05	0.05	Europe	3

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
1,2,3,7,8,9-HxCDD (continued)	Beef and veal	19	10	ND-0.86	0.205	0.135	World Wide	5,8,11,12
	Beef and veal	11	3	ND-0.616	0.206	0.134	North America	11,12
	Beef and veal	8	7	ND-0.86	0.20	0.14	Europe	5,8
	Pork	13	2	0.009-0.282	0.093	0.067	World Wide	3,5,11,12
	Pork	9	1	ND-0.282	0.121	0.102	North America	11,12
	Pork	4	1	0.009-0.038	0.031	0.027	Europe	3,5
	Chicken	12	5	ND-4.3	0.153	0.098	World Wide	3,5,11,12
	Chicken	9	2	ND-4.3	0.174	0.101	North America	11,12
	Chicken	3	3	0.075-0.090	0.090	0.090	Europe	3,5
Heptachlorodibenzo-p-dioxins (MW = 425.31)								
1,2,3,4,6,7,8-HpCDD	Milk	20	13	ND-0.96	0.13	0.10	World Wide	2,3,5,7
	Milk	20	13	ND-0.96	0.13	0.10	Europe	2,3,5,7
	Dairy products	25	25	0.24-5.88	1.139	0.895	World Wide	3,5,8,10
	Dairy products	5	5	0.18-5.88	2.162	1.307	North America	10
	Dairy products	20	20	0.24-1.38	0.883	0.814	Europe	3,5,8
	Eggs	9	1	ND-0.04	0.10	0.097	World Wide	3,11
	Eggs	8	0	ND(0.08-0.42)	0.11	0.11	North America	11
	Eggs	1	1	0.04	0.04	0.04	Europe	3
	Beef and veal	19	18	ND-12.065	1.446	0.840	World Wide	5,8,11,12
	Beef and veal	11	10	ND-12.065	1.925	0.959	North America	11,12

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
1,2,3,4,6,7,8-HpCDD (continued)	Beef and veal	8	8	0.156-2.97	0.79	0.70	Europe	5,8
	Pork	13	10	ND-8.197	1.881	0.758	World Wide	3,5,11,12
	Pork	9	9	0.46-8.197	2.647	1.611	North America	11,12
	Pork	4	1	ND-0.32	0.16	0.14	Europe	3,5
	Chicken	12	11	ND-5.28	0.975	0.522	World Wide	3,5,11,12
	Chicken	9	8	ND-5.28	1.049	0.463	North America	11,12
	Chicken	3	3	0.68-0.90	0.75	0.75	Europe	3,5
Octachlorodibenzo-p-dioxin (MW = 460.76)								
1,2,3,4,6,7,8,9-OCDD	Milk	20	20	0.12-0.82	0.29	0.28	World Wide	2,3,5,7
	Milk	20	20	0.12-0.82	0.29	0.28	Europe	2,3,5,7
	Dairy products	20	20	0.66-28.35	5.13	4.32	World Wide	3,5,8
	Dairy products	20	20	0.66-28.35	5.13	4.32	Europe	3,5,8
	Eggs	9	2	ND-1.30	0.68	0.66	World Wide	3,11
	Eggs	8	1	ND-1.30	0.61	0.61	North America	11
	Eggs	1	1	1.2	1.2	1.2	Europe	3
	Beef and veal	19	18	ND-15.825	2.201	1.522	World Wide	5,8,11,12
	Beef and veal	11	10	ND-15.825	2.911	1.835	North America	11,12
	Beef and veal	8	8	0.63-4.69	1.22	1.18	Europe	5,8
	Pork	13	13	0.81-50.742	11.367	8.886	World Wide	3,5,11,12
	Pork	9	9	2.06-50.742	15.693	5.159	North America	11,12

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
1,2,3,4,6,7,8,9-OCDD (continued)	Pork	4	4	0.81-2.85	1.64	1.52	Europe	3,5
	Chicken	12	11	ND-14.4	4.248	2.223	World Wide	3,5,11,12
	Chicken	9	8	ND-14.4	4.246	1.887	North America	11,12
	Chicken	3	3	2.1-7.8	4.25	3.63	Europe	3,5
TEQs for Dibenzodioxins	Milk				0.0421		World Wide	
	Milk				0.0018,0.12[d]	0.12[d]	North America	
	Milk				0.0431		Europe	
	Dairy products				0.2714		World Wide	
	Dairy products				0.2029		North America	
	Dairy products				0.2873		Europe	
	Eggs				0.0842		World Wide	
	Eggs				0.0812		North America	
	Eggs				0.0736		Europe	
	Beef and veal				0.2473		World Wide	
	Beef and veal				0.2892		North America	
	Beef and veal				0.2341		Europe	
	Pork				0.1692		World Wide	
	Pork				0.1979		North America	
	Pork				0.2255		Europe	
	Chicken				0.2298		World Wide	

Table B-25. Mean Background Levels of Dioxins in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. range[b]	Arithmetic mean[c]	Geometric mean[c]	Location	Ref. no.(s)
TEQs	Chicken				0.1587		North America	
for Dibenzodioxins	Chicken				0.1713		Europe	

Footnote References

[a] Dairy products include butter, cheeses, and cow cream.
[b] Samples analyzed on a fat weight basis were adjusted to a wet weight basis by multiplying the value by the percentage of fat contained in the sample: beef, 19.0; butter, 81.0; cheese, 33.0; chicken, 15.0; cow cream, 37.0; eggs, 10.0; milk, 3.3; pork, 15.0; Swiss cheese, 27.0; and veal, 6.7 (USDA, 1979-1984).
[c] Means were taken from all sites except near incinerators, South Vietnam, and pork samples from the USSR because, the sites were possibly contaminated.
[d] Value was reported as total 2,3,7,8-TCDD toxic equivalents (U.S., EPA 1991b).

NOTES: One-half the limit of detection was used in calculating the means where applicable. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).

ND = not detected (limit of detection)

Sources: 2. Rappe et al. (1987)
3. Beck et al. (1989)
4. LaFleur et al. (1990)
5. Furst et al. (1990)
7. Startin et al. (1990)
8. Schecter et al. (1990)
10. Schecter et al. (1992)
11. Stanley and Bauer (1989)

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (wet wt. ppt)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
Tetrachlorodibenzofurans (MW=305.98)								
2,3,7,8-TCDF	Milk	21	3	ND-0.33	0.057	0.023	World Wide	2,3,4,5,7
	Milk	1	0	ND(0.001)	0.0005	0.0005	North America	4
	Milk	20	3	ND-0.33	0.059	0.026	Europe	2,3,5,7
	Dairy products	25	10	ND-0.36	0.214	0.164	World Wide	3,5,8,10
	Dairy products	5	5	0.02-0.15	0.082	0.068	North America	10
	Dairy products	20	5	ND-0.36	0.247	0.204	Europe	3,5,8
	Eggs	9	2	ND-0.11	0.021	0.013	World Wide	3,11
	Eggs	8	1	ND-0.01	0.01	0.01	North America	11
	Eggs	1	1	0.11	0.11	0.11	Europe	3
	Beef and veal	22	9	ND-0.30	0.044	0.022	World Wide	4,5,8,11,12
	Beef and veal	14	7	ND-0.30	0.058	0.023	North America	4,11,12
	Beef and veal	8	1	ND-0.095	0.021	0.020	Europe	5,8
	Pork	16	5	ND-0.065	0.024	0.020	World Wide	3,4,5,11,12
	Pork	11	4	ND-0.065	0.025	0.013	North America	4,11,12
	Pork	4	1	0.016-0.022	0.021	0.020	Europe	3,5
	Chicken	12	5	ND-0.60	0.119	0.058	World Wide	3,5,11,12
	Chicken	9	2	ND-0.10	0.037	0.032	North America	11,12
	Chicken	3	3	0.18-0.60	0.37	0.37	Europe	3,5

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
Pentachlorodibenzofurans (MW = 340.42)								
1,2,3,7,8-PeCDF	Milk	20	3	ND-0.043	0.009	0.008	World Wide	2,3,5,7
	Milk	20	3	ND-0.043	0.009	0.008	Europe	2,3,5,7
	Dairy products	25	5	ND-0.212	0.077	0.057	World Wide	3,5,8,10
	Dairy products	5	1	ND-0.04	0.022	0.016	North America	10
	Dairy products	20	4	ND-0.212	0.088	0.073	Europe	3,5,8
	Eggs	9	1	ND-0.06	0.027	0.021	World Wide	3,11
	Eggs	8	0	ND(0.01-0.1)	0.023	0.021	North America	11
	Eggs	1	1	0.06	0.06	0.06	Europe	3
	Beef and veal	19	2	ND-0.028	0.032	0.017	World Wide	5,8,11,12
	Beef and veal	11	1	ND-0.01	0.043	0.019	North America	11,12
	Beef and veal	8	1	ND-0.028	0.016	0.014	Europe	5,8
	Pork	13	2	ND-0.009	0.037	0.027	World Wide	3,5,11,12
	Pork	9	1	ND-0.009	0.046	0.038	North America	11,12
	Pork	4	1	ND-0.002	0.017	0.012	Europe	3,5
	Chicken	12	2	ND-0.18	0.032	0.017	World Wide	3,5,11,12
	Chicken	9	0	ND(0.018-0.1)	0.019	0.015	North America	11,12
	Chicken	3	2	ND-0.18	0.071	0.028	Europe	3,5

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
2,3,4,7,8-PeCDF	Milk	20	20	0.028-0.15	0.066	0.059	World Wide	2,3,5,7
	Milk	20	20	0.028-0.15	0.066	0.059	Europe	2,3,5,7
	Dairy products	25	20	ND-1.431	0.549	0.368	World Wide	3,5,8,10
	Dairy products	5	5	0.02-0.25	0.132	0.098	North America	10
	Dairy products	20	15	ND-1.431	0.653	0.512	Europe	3,5,8
	Eggs	9	1	ND-0.08	0.023	0.019	World Wide	3,11
	Eggs	8	0	ND(0.01-0.07)	0.016	0.015	North America	11
	Eggs	1	1	0.08	0.08	0.08	Europe	3
	Beef and veal	19	11	ND-1.783	0.317	0.145	World Wide	5,8,11,12
	Beef and veal	11	3	ND-1.783	0.211	0.064	North America	11,12
	Beef and veal	8	8	0.18-0.74	0.46	0.44	Europe	5,8
	Pork	13	2	ND-0.039	0.037	0.032	World Wide	3,5,11,12
	Pork	9	1	ND-0.039	0.045	0.041	North America	11,12
	Pork	4	1	ND(0.045)-0.012	0.020	0.019	Europe	3,5
	Chicken	12	4	ND-0.30	0.066	0.030	World Wide	3,5,11,12
	Chicken	9	1	ND-0.01	0.018	0.015	North America	11,12
	Chicken	3	3	0.105-0.30	0.21	0.21	Europe	3,5
Hexachlorodibenzofurans (MW=374.87)								
1,2,3,4,7,8-HxCDF	Milk	20	20	0.013-0.099	0.037	0.032	World Wide	2,3,5,7

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
1,2,3,4,7,8-HxCDF (continued)	Milk	20	20	0.013-0.099	0.037	0.032	Europe	2,3,5,7
	Dairy products	25	10	ND-2.014	0.449	0.313	World Wide	3,5,8,10
	Dairy products	5	5	0.06-0.93	0.450	0.332	North America	10
	Dairy products	20	5	ND-2.014	0.449	0.309	Europe	3,5,8
	Eggs	9	1	ND-0.04	0.069	0.061	World Wide	3,11
	Eggs	8	0	ND(0.04-0.25)	0.073	0.065	North America	11
	Eggs	1	1	0.04	0.04	0.04	Europe	3
	Beef and veal	19	8	ND-4.846	0.365	0.122	World Wide	5,8,11
	Beef and veal	11	3	ND-4.846	0.51	0.099	North America	11
	Beef and veal	8	5	ND-0.41	0.17	0.16	Europe	5,8
	Pork	13	2	ND-0.108	0.086	0.057	World Wide	3,5,11
	Pork	9	1	ND-0.108	0.115	0.088	North America	11
	Pork	4	1	ND-0.022	0.022	0.022	Europe	3,5
	Chicken	12	3	ND-0.28	0.058	0.044	World Wide	3,5,11
	Chicken	9	1	ND-0.009	0.035	0.031	North America	11
	Chicken	3	2	ND-0.28	0.13	0.13	Europe	3,5
1,2,3,6,7,8-HxCDF	Milk	20	20	0.009-0.066	0.026	0.023	World Wide	2,3,5,7
	Milk	20	20	0.009-0.066	0.026	0.023	Europe	2,3,5,7
	Dairy products	25	10	ND-0.57	0.255	0.184	World Wide	3,5,8,10

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
1,2,3,6,7,8-HxCDF (continued)	Dairy products	5	5	0.02-0.34	0.156	0.111	North America	10
	Dairy products	20	5	ND-0.57	0.280	0.208	Europe	3,5,8
	Eggs	9	1	ND-0.03	0.073	0.057	World Wide	3,11
	Eggs	8	0	ND(0.04-0.31)	0.078	0.061	North America	11
	Eggs	1	1	0.03	0.03	0.03	Europe	3
	Beef and veal	19	7	ND-0.34	0.087	0.060	World Wide	5,8,11,12
	Beef and veal	11	2	ND-0.199	0.063	0.039	North America	11,12
	Beef and veal	8	5	ND-0.34	0.12	0.11	Europe	5,8
	Pork	13	2	ND-0.031	0.038	0.033	World Wide	3,5,11,12
	Pork	9	1	ND-0.031	0.046	0.026	North America	11,12
	Pork	4	1	ND(0.045)-0.01	0.019	0.018	Europe	3,5
	Chicken	12	4	ND-0.12	0.04	0.034	World Wide	3,5,11,12
	Chicken	9	5	ND-0.008	0.03	0.045	North America	11,12
	Chicken	3	3	0.045-0.12	0.07	0.07	Europe	3,5
1,2,3,7,8,9-HxCDF	Milk	7	0	ND(0.002-0.012)	0.008	0.008	World Wide	7
	Milk	7	0	ND(0.002-0.012)	0.008	0.008	Europe	7
	Dairy products	9	0	ND-0.08	0.031	0.021	World Wide	8,10
	Dairy products	5	0	ND-0.05	0.024	0.017	North America	10
	Dairy products	4	0	ND(0.005-0.08)	0.040	0.026	Europe	8

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
1,2,3,7,8,9-HxCDF (continued)	Eggs	8	0	ND(0.05-0.58)	0.13	0.092	World Wide	11
	Eggs	8	0	ND(0.05-0.58)	0.13	0.092	North America	11
	Beef and veal	12	0	ND(0.002-0.29)	0.053	0.024	World Wide	8,11,12
	Beef and veal	11	0	ND(0.002-0.29)	0.058	0.028	North America	11,12
	Beef and veal	1	0	ND(0.005)	0.005	0.005	Europe	8
	Pork	9	0	ND(0.076-0.16)	0.056	0.032	World Wide	11,12
	Pork	9	0	ND(0.076-0.16)	0.056	0.032	North America	11,12
	Chicken	9	0	ND(0.012-0.14)	0.040	0.044	World Wide	11,12
	Chicken	9	0	ND(0.012-0.14)	0.040	0.044	North America	11,12
2,3,4,6,7,8-HxCDF	Milk	20	19	ND-0.073	0.028	0.024	World Wide	2,3,5,7
	Milk	20	19	ND-0.073	0.028	0.024	Europe	2,3,5,7
	Dairy products	25	10	ND-0.57	0.247	0.168	World Wide	3,5,8,10
	Dairy products	5	5	0.01-0.15	0.096	0.069	North America	10
	Dairy products	20	5	ND-0.57	0.285	0.209	Europe	3,5,8
	Eggs	9	1	ND-0.17	0.12	0.087	World Wide	3,11
	Eggs	8	0	ND(0.04-0.52)	0.12	0.080	North America	11
	Eggs	1	1	0.17	0.17	0.17	Europe	3
	Beef and veal	19	8	ND-0.34	0.109	0.080	World Wide	5,8,11,12
	Beef and veal	11	3	ND-0.177	0.072	0.058	North America	11,12

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
2,3,4,6,7,8-HxCDF (continued)	Beef and veal	8	5	ND-0.34	0.16	0.12	Europe	5,8
	Pork	13	2	ND-0.029	0.043	0.037	World Wide	3,5,11,12
	Pork	9	1	ND-0.029	0.054	0.052	North America	11,12
	Pork	4	1	ND(0.022)-0.008	0.019	0.017	Europe	3,5
	Chicken	12	2	ND-0.18	0.048	0.038	World Wide	3,5,11,12
	Chicken	9	0	ND(0.01-0.13)	0.036	0.029	North America	11,12
	Chicken	3	2	ND-0.18	0.085	0.079	Europe	3,5
Heptachlorodibenzofurans (MW = 409.31)								
1,2,3,4,6,7,8-HpCDF	Milk	20	12	ND-0.20	0.041	0.036	World Wide	2,3,5,7
	Milk	20	12	ND-0.20	0.041	0.036	Europe	2,3,5,7
	Dairy products	25	6	ND-1.76	0.276	0.182	World wide	3,5,8,10
	Dairy products	5	5	0.1-1.76	0.712	0.502	North America	10
	Dairy products	20	1	ND-0.28	0.167	0.141	Europe	3,5,8
	Eggs	9	2	ND-0.07	0.14	0.11	World Wide	3,11
	Eggs	8	1	ND-0.07	0.15	0.12	North America	11
	Eggs	1	1	0.06	0.06	0.06	Europe	3
	Beef and veal	19	9	ND-2.702	0.314	0.163	World Wide	5,8,11,12
	Beef and veal	11	5	ND-2.702	0.395	0.186	North America	11,12
	Beef and veal	8	4	ND-0.97	0.20	0.14	Europe	5,8

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
1,2,3,4,6,7,8-HpCDF (continued)	Pork	13	9	ND-1.59	0.516	0.380	World Wide	3,5,11
	Pork	9	8	ND-1.59	0.654	0.502	North America	11
	Pork	4	1	ND-0.16	0.20	0.20	Europe	3,5
	Chicken	12	10	ND-3.69	0.481	0.158	World Wide	3,5,11
	Chicken	9	7	ND-3.69	0.611	0.192	North America	11
	Chicken	3	3	0.075-0.12	0.090	0.088	Europe	3,5
1,2,3,4,7,8,9-HpCDF	Milk	7	0	ND(0.01-0.067)	0.026	0.026	World Wide	7
	Milk	7	0	ND(0.01-0.067)	0.026	0.026	Europe	7
	Dairy products	9	1	ND-0.17	0.082	0.058	World wide	8,10
	Dairy products	5	1	ND-0.17	0.095	0.072	North America	10
	Dairy products	4	0	ND(0.01-0.13)	0.066	0.045	Europe	8
	Eggs	8	0	ND(0.04-1.10)	0.21	0.21	World Wide	11
	Eggs	8	0	ND(0.04-1.10)	0.21	0.21	North America	11
	Beef and veal	12	2	ND-0.118	0.119	0.061	World Wide	8,11,12
	Beef and veal	11	2	ND-0.118	0.129	0.071	North America	11,12
	Beef and veal	1	0	ND(0.01)	0.01	0.01	Europe	8
	Pork	9	1	ND-0.097	0.209	0.193	World Wide	11,12
	Pork	9	1	ND-0.097	0.209	0.193	North America	11,12

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
1,2,3,4,7,8,9-HpCDF (continued)	Chicken	9	0	ND(0.01-0.62)	0.088	0.054	World Wide	11,12
	Chicken	9	0	ND(0.01-0.62)	0.088	0.054	North America	11,12
Octachlorodibenzofurans (MW=444.76)								
1,2,3,4,6,7,8,9-OCDF	Milk	20	9	ND-0.20	0.048	0.045	World Wide	2,3,5,7
	Milk	20	9	ND-0.20	0.048	0.045	Europe	2,3,5,7
	Dairy products	20	11	ND-1.39	0.253	0.185	World Wide	3,5,8
	Dairy products	20	11	ND-1.39	0.253	0.185	Europe	3,5,8
	Eggs	9	1	ND-0.02	0.22	0.14	World Wide	3,11
	Eggs	8	0	ND(0.05-1.30)	0.24	0.14	North America	11
	Eggs	1	1	0.02	0.02	0.02	Europe	3
	Beef and veal	19	NR	ND-1.073	0.154	0.078	World Wide	5,8,11,12
	Beef and veal	11	3	ND-1.073	0.224	0.115	North America	11,12
	Beef and veal	8	NR	ND-0.34	0.059	0.045	Europe	5,8
	Pork	13	7	ND-1.40	0.282	0.132	World Wide	3,5,11,12
	Pork	9	6	ND-1.40	0.393	0.261	North America	11,12
	Pork	4	1	ND-0.062	0.032	0.029	Europe	3,5
	Chicken	12	6	ND-3.90	0.464	0.141	World Wide	3,5,11,12
	Chicken	9	3	ND-3.90	0.575	0.146	North America	11,12
	Chicken	3	3	0.09-0.22	0.13	0.13	Europe	3,5

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
TEQs for Dibenzofurans	Milk				0.0498		World Wide	
	Milk				0.00005		North America	
	Milk				0.0500		Europe	
	Dairy products				0.4018		World Wide	
	Dairy products				0.1560		North America	
	Dairy products				0.4636		Europe	
	Eggs				0.0579		World Wide	
	Eggs				0.0541		North America	
	Eggs				0.0786		Europe	
	Beef and veal				0.2304		World Wide	
	Beef and veal				0.1892		North America	
	Beef and veal				0.2806		Europe	
	Pork				0.0526		World Wide	
	Pork				0.0634		North America	
	Pork				0.0210		Europe	
	Chicken				0.0713		World Wide	
	Chicken				0.0353		North America	
	Chicken				0.1751		Europe	

Table B-26. Mean Background Levels of Dibenzofurans in Food Products (ppt) (continued)

Footnote References

[a] Dairy products include butter, cheeses, and cow cream.
[b] Samples analyzed on a fat weight basis were adjusted to a wet weight basis by multiplying the value by the percentage of fat contained in the sample: beef, 19.0; butter, 81.0; cheese, 33.0; chicken, 15.0; cow cream, 37.0; eggs, 10.0; milk, 3.3; pork, 15.0; Swiss cheese, 27.0; and veal, 6.7 (USDA, 1979-1984).
[c] Means were taken from all sites except near incinerators, South Vietnam, and pork samples from the USSR because, the sites were possibly contaminated.
[d] World Wide includes North American and Europe only.

NOTES: One-half the limit of detection was used in calculating the means where applicable. Therefore, it is possible to have mean concentrations greater than the range (e.g., reported detection limit for nondetects greater than the positive sample).

ND = not detected (limit of detection)

Sources:

2. Rappe et al. (1987)
3. Beck et al. (1989)
4. LaFleur et al. (1990)
5. Furst et al. (1990)
7. Startin et al. (1990)
8. Schecter et al. (1990)
10. Schecter et al. (1992)
11. Stanley and Bauer (1989)

Table B-27. Mean Background Levels of PCBs in Food Products (wet wt. ppt)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[d]	Location[e]	Ref. no(s).
Pentachloro-PCB (MW = 326.44)								
2,3,3',4,4-PeCB	Pork	1	1	54	54	54	World wide	1
	Pork	1	1	54	54	54	North America	1
	Chicken	4	4	25	25	25	World wide	1
	Chicken	4	4	25	25	25	North America	1
	Beef/veal	6	6	10-19	18.83	16.4	World wide	1
	Beef/veal	6	6	10-19	18.83	16.4	North America	1
	Dairy	25	25	10-116	47.12	34.626	World wide	1
	Dairy	25	25	10-116	47.12	34.626	North America	1
	Eggs	4	4	34	34	34	World wide	1
	Eggs	4	4	34	34	34	North America	1
2,3',4,4',5-PeCB	Pork	4	4	55	55	55	World wide	1
	Pork	4	4	55	55	55	North America	1
	Chicken	4	4	81	81	81	World wide	1
	Chicken	4	4	81	81	81	North America	1
	Beef/veal	15	15	190-595	71	63.26	World wide	1
	Beef/veal	15	15	190-595	71	63.26	North America	1
	Dairy	36	36	19-487	153.86	90.5	World wide	1
	Dairy	36	36	19-487	153.86	90.5	North America	1

Table B-27. Mean Background Levels of PCBs in Food Products (wet wt. ppt) (continued)

Chemical	Sample type[a]	Number samples	Number positive samples	Conc. Range[b]	Arithmetic mean[c]	Geometric mean[c]	Location[d]	Ref. no(s).
2,3',4,4',5-PeCB cont.	Eggs	5	5	99	99	99	World wide	1
	Eggs	5	5	99	99	99	North America	1
Hexachloro-PCB (MW=360.88)								
2,3,3',4,4',5-HxCB	Pork	2	2	9	9	9	World wide	1
	Pork	2	2	9	9	9	North America	1
	Chicken	3	3	16	16	16	World wide	1
	Chicken	3	3	16	16	16	North America	1
	Beef/veal	8	8	7-14	10.75	10.24	World wide	1
	Beef/veal	8	8	7-14	10.75	10.24	North America	1
	Dairy	21	21	7-63	29.57	23.32	World wide	1
	Dairy	21	21	7-63	29.57	23.32	North America	1
	Eggs	3	3	24	24	24	World wide	1
	Eggs	3	3	24	24	24	North America	1
Heptachloro-PCB (MW=396.33)								
2,3,3',4,4',5,5'-HpCB	Beef/Veal	1	1	10	10	10	World wide	1
	Beef/Veal	1	1	10	10	10	North America	1
	Dairy	2	2	7-10	8.5	8.37	World wide	1
	Dairy	2	2	7-10	8.5	8.37	North America	1

Table B-27. Mean Background Levels of PCBs in Food Products (wet wt. ppt) (continued)

Footnote References

[a] Dairy products include butter, cheeses, and cow cream.
[b] Samples analyzed on a fat weight basis were adjusted to a wet weight basis by multiplying the value by the percentage of fat contained in the sample: beef, 19.0; butter, 81.0; cheese, 33.0; chicken, 15.0; cow cream, 37.0; eggs, 10.0; milk, 3.3; pork, 15.0; Swiss cheese, 27.0; and veal, 6.7 (USDA, 1979-1984).
[c] Means were taken from all sites except near incinerators, South Vietnam, and pork samples from the USSR because, the sites were possibly contaminated.
[d] World Wide includes North American and Europe only.

Notes: One-half the limit of detection was used in calculating the means where applicable.
ND = not detected (limit of detection)

Sources: 1. Mes, et al. (1991).

Table B-28. Mean Rural/Urban Background Environmental Levels of Dioxins in Air (pg/m^3)

Chemical	Number samples[a]	Number positive samples	Concentration range	Arithmetic mean[b]	Geometric mean[b]	Location[c]	Ref. no.
Tetrachlorodibenzo-p-dioxins (MW=321.98)							
2,3,7,8-TCDD	78	8	ND-0.08	0.0100	0.0052	World Wide	1,3,4,5,7,9,11,12,14
	73	3	ND-0.08	0.0107	0.0063	North America	1,3,4,5,9,11,14
	5	5	0.0002-0.007	0.0004	0.0003	Europe	7,12
TCDDs	81	29	ND-0.18	0.0429	0.0318	World Wide	1,4,5,7,9,11,12,14
	76	24	ND-0.18	0.0435	0.0322	North America	1,4,5,9,11,14
	5	5	0.0057-0.05	0.0325	0.0258	Europe	7,12
Pentachlorodibenzo-p-dioxins (MW=356.42)							
1,2,3,7,8-PeCDD	73	16	ND-0.14	0.0297	0.0125	World Wide	1,3,4,5,7,9,12,13,14
	68	11	ND-0.14	0.0316	0.0141	North America	1,3,4,5,9,13,14
	5	5	0.0007-0.006	0.0036	0.0027	Europe	7,12
PeCDDs	90	31	ND-0.89	0.0836	0.0559	World Wide	1,4,5,7,9,11,12,14
	85	26	ND(0.89)	0.0843	0.0557	North America	1,4,5,9,11,14
	5	5	0.019-0.11	0.0716	0.0592	Europe	7,12
Hexachlorodibenzo-p-dioxins (MW=390.87)							
1,2,3,4,7,8-HxCDD	73	20	ND-0.14	0.0231	0.0164	World Wide	1,3,4,5,7,9,12,13,14
	68	15	ND-0.14	0.0246	0.0192	North America	1,3,4,5,9,12,13,14
	5	5	0.0006-0.004	0.0025	0.0020	Europe	7,12
1,2,3,6,7,8-HxCDD	73	35	ND-0.39	0.0350	0.0264	World Wide	1,3,4,5,7,9,12,13,14
	68	30	ND-0.39	0.0372	0.0304	North America	1,3,4,5,9,13,14
	5	5	0.0009-0.008	0.0050	0.0038	Europe	7,12
1,2,3,7,8,9-HxCDD	73	30	ND-0.35	0.0458	0.0327	World Wide	1,3,4,5,7,9,12,13,14
	68	26	ND-0.35	0.0489	0.0400	North America	1,3,4,5,9,13,14
	5	4	ND-0.0052	0.0031	0.0021	Europe	7,12

Table B-28. Mean Background Environmental Levels of Dioxins in Air (pg/m^3) (continued)

Chemical	Number samples[a]	Number positive samples	Concentration range	Arithmetic mean[b]	Geometric mean[b]	Location[c]	Ref. no.
HxCDDs	90	65	ND-3.2	0.3067	0.2010	World Wide	1,4,5,7,9,11,12,14
	85	60	ND-3.2	0.3210	0.2179	North America	1,4,5,9,11,14
	5	5	0.014-0.1	0.0644	0.0506	Europe	7,12
Heptachlorodibenzo-p-dioxins (MW=425.31)							
1,2,3,4,6,7,8-HpCDD	73	58	ND-8.4	0.5474	0.3370	World Wide	1,3,4,5,7,9,12,13,14
	68	53	ND-8.4	0.5828	0.3881	North America	1,3,4,5,9,13,14
	5	5	0.012-0.1	0.0660	0.0494	Europe	7,12
HpCDDs	90	74	ND-8.4	0.9738	0.6400	World Wide	1,4,5,7,9,11,12,14
	85	69	ND-8.4	1.0231	0.7109	North America	1,4,5,9,11,14
	5	5	0.03-0.2	0.1364	0.1072	Europe	7,12
Octachlorodibenzo-p-dioxin (MW=460.76)							
OCDD	73	63	ND-29.5	2.6551	1.7663	World Wide	1,3,4,5,7,9,10,11,12,14
	68	58	ND-29.5	2.8386	2.1426	North America	1,3,4,5,9,10,11,14
	5	5	0.041-0.23	0.1598	0.1277	Europe	7,12
TEQs for				0.0434		World Wide	
				0.0462		North America	
Dibenzodioxins				0.00408		Europe	

Footnote References

[a] The number of positive samples from Hunt and Maisel (1990) were not included because they were not reported.

[b] Means were taken from rural, urban, and pristine sites.
Industrial, sites were not used because they were assumed to be contaminated.

[c] Worldwide includes Europe and North America only.

NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)

Sources:
1. Smith, et al. (1989).
3. Maisel and Hunt (1990).
4. Hunt and Maisel (1990).
5. CDEP (1988).
7. Naf, et al. (1990)
9. Edgerton, et al. (1989).
10. Eitzer and Hites (1989).
11. Smith, et al. (1990).
12. Broman, et al. (1991).
13. Eitzer and Hites (1989).
14. Hunt, et al. (1990).

Table B-29. Mean Rural/Urban Background Environmental Levels of Dibenzofurans in Air (pg/m^3)

Chemical	Number samples	Number positive samples[a]	Conc. range	Arithmetic mean[b]	Geometric mean[b]	Location[c]	Ref. no(s).
Tetrachlorodibenzofurans (MW=305.98)							
2,3,7,8-TCDF	73	50	ND-1.24	0.1128	0.0489	World Wide	1,3,4,5,9,11,14
	73	50	ND-1.24	0.1128	0.0489	North America	1,3,4,5,9,11,14
TCDFs	90	68	ND-8.81	0.6343	0.3787	World Wide	1,4,5,7,9,11,12,14
	85	63	ND-8.81	0.6600	0.3995	North America	1,4,5,9,11,14
	5	5	0.018-0.33	0.1976	0.1529	Europe	7,12
Pentachlorodibenzofurans (MW=340.42)							
1,2,3,7,8-PeCDF	67	17	ND-1.90	0.0498	0.0220	World Wide	1,3,4,5,9,14
	67	17	ND-1.90	0.0498	0.0220	North America	1,3,4,5,9,14
2,3,4,7,8-PeCDF	72	27	ND-0.16	0.0274	0.0230	World Wide	1,3,4,5,7,9,12,14
	68	22	ND-0.16	0.0287	0.0255	North America	1,3,4,5,9,14
	5	5	0.0012-0.02	0.0098	0.0059	Europe	7,12
PeCDFs	90	67	ND-3.61	0.4234	0.2963	World Wide	1,4,5,7,9,11,12,14
	85	62	ND-3.61	0.4424	0.3200	North America	1,4,5,9,11,14
	5	5	0.026-0.17	0.1012	0.0799	Europe	7,12
Hexachlorodibenzofurans (MW=374.87)							
1,2,3,4,7,8-HxCDF	67	30	ND-0.41	0.0604	0.0562	World Wide	1,3,4,5,9,14
	67	30	ND-0.41	0.0604	0.0562	North America	1,3,4,5,9,14
1,2,3,6,7,8-HxCDF	72	30	ND-0.8	0.0548	0.0392	World Wide	1,3,4,5,7,9,12,14
	67	25	ND-0.8	0.0585	0.0463	North America	1,3,4,5,9,14
	5	5	0.0014-0.008	0.0051	0.0042	Europe	7,12
1,2,3,7,8,9-HxCDF	73	8	ND-0.097	0.0147	0.0070	World Wide	1,3,4,5,7,9,12,13, 14
	68	3	ND-0.097	0.0157	0.0085	North America	1,3,4,5,9,13,14
	5	5	0.0001-0.0008	0.0006	0.0005	Europe	7,12
2,3,4,6,7,8-HxCDF	73	29	ND-0.3	0.0420	0.0332	World Wide	1,3,4,5,7,9,12,13, 14
	68	24	ND-0.3	0.0448	0.0395	North America	1,3,4,5,9,13,14
	5	5	0.0009-0.0063	0.0039	0.0031	Europe	7,12

Table B-29. Mean Rural/Urban Background Environmental Levels Dibenzofurans in Air (pg/m³) (continued)

Chemical	Number samples	Number positive samples[a]	Conc. range	Arithmetic mean[b]	Geometric mean[b]	Location[c]	Ref. no(s).
HxCDFs	90	67	ND-2.15	0.3616	0.2947	World Wide	1,4,5,7,9,11,12,14
	85	62	ND-2.15	0.3797	0.3295	North America	1,4,5,9,11,14
	5	5	0.015-0.08	0.0528	0.0442	Europe	7,12
Heptachlorodibenzofurans (MW=409.31)							
1,2,3,4,6,7,8-HpCDF	73	42	ND-1.20	0.1995	0.1700	World Wide	1,3,4,5,7,9,12,13, 14
	68	37	ND-1.20	0.2102	0.1817	North America	1,3,4,5,9,13,14
	5	5	0.011-0.09	0.0542	0.0686	Europe	7,12
1,2,3,4,7,8,9-HpCDF	70	19	ND-0.3	0.0279	0.0218	World Wide	3,4,5,7,9,12,13,14
	65	15	ND-0.3	0.0299	0.0272	North America	3,4,5,9,13,14
	5	4	ND-0.004	0.0019	0.0012	Europe	7,12
HpCDFs	90	60	ND-1.58	0.3196	0.2528	World Wide	1,4,5,7,9,11,12,14
	85	55	ND-1.58	0.3343	0.2763	North America	1,4,5,9,11,14
	5	5	0.015-0.11	0.0704	0.0556	Europe	7,12
Octachlorodibenzofurans (MW=444.76)							
OCDFs	89	51	ND-0.70	0.1597	0.1271	World Wide	1,3,4,5,7,9,11,12, 14
	84	46	ND-0.70	0.1686	0.1528	North America	1,3,4,5,9,11,14
	5	5	0.0009-0.016	0.0094	0.0057	Europe	7,12
TEQs for				0.0471		World Wide	
				0.0486		North America	
Dibenzofurans				0.0064		Europe	

Table B-29. Mean Rural/Urban Background Environmental Levels Dibenzofurans in Air (pg/m³) (continued)

Footnote References

[a] The number of positive samples from Hunt and Maisel (1990) were not included because they were not reported.
[b] Means were taken from urban and pristine sites.
Industrial, sites were not used because they were assumed to be contaminated.
[c] Worldwide includes Europe and North America only.
NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)

Sources:

1. Smith, et al. (1989).
3. Maisel and Hunt (1990).
4. Hunt and Maisel (1990).
5. CDEP (1988)
7. Naf, et al. (1991).
9. Edgerton, et al. (1989).
11. Smith, et al. (1990).
12. Broman, et al. (1990).
13. Eitzer and Hites (1989).
14. Hunt, et al. (1990).

Table B-30. Mean Background Environmental Levels of PCBs in Air (pg/m^3)

Chemical	Number samples	Number positive samples	Conc. range	Arithmetic mean[a]	Geometric Mean[a]	Location	Ref. no(s).
Pentachloro-PCB (MW=326.44)							
2,3,4,4'5-PeCB	143	143	2.3	2.3	2.3	World wide	14
	143	143	2.3	2.3	2.3	North America	14
2,3,4,4',5-PeCB	143	143	1.2	1.2	1.2	World wide	14
	143	143	1.2	1.2	1.2	North America	14
2,3,3',4,4'-PeCB	143	143	0.6	0.16	0.16	World wide	14
	143	143	0.6	0.16	0.16	North America	14
Hexachloro-PCB (MW=360.88)							
2,3,3',4,4',5-HxCB	143	143	0.07	0.07	0.07	World wide	14
	143	143	0.07	0.07	0.07	North America	14
Heptachloro-PCB (MW=396.33)							
2,3,3'4,4'5,5'-HpCB	143	143	0.01	0.01	0.01	World wide	14
	143	143	0.01	0.01	0.01	North America	14

Footnote References

[a] Means were taken from urban and pristine sites.
Industrial, sites were not used because they were assumed to be contaminated.

NOTES: One-half the limit of detection was used in calculating the means where applicable.
ND = non-detected (limit of detection)

Sources: 14. Hoff, et al. (1992).

APPENDIX C. BIOAVAILABILITY OF DIOXINS

C.1 Bioavailability Data

Umbreit et al. (1985, 1986a,b) conducted experiments in guinea pigs, administering 2,3,7,8-TCDD in corn oil, 2,3,7,8-TCDD added to chemically decontaminated soil, or soil from two industrial sites in Newark, New Jersey (a manufacturing site and a salvage site) contaminated with CDDs. 2,3,7,8-TCDD was the principal lower chlorinated isomer (dioxin or furan) present in the soil from the manufacturing site (for which a chemical analysis was presented). Soil from the manufacturing site was found to have 1,500 to 2,500 ppb 2,3,7,8-TCDD under soxhlet extraction; release under ambient temperature manual solvent extraction was much lower, reported as "> 2.5 ppb." The soil from the salvage site was reported as approximately 180 ppb 2,3,7,8-TCDD under soxhlet extraction.

In this study, groups of two or four male and two or four female guinea pigs received single gavage doses of the test materials and were observed until death or sacrifice at 60 days. 2,3,7,8-TCDD in corn oil or in recontaminated soil (6 g/kg in both) proved highly toxic, without similar toxicity being observed in animals treated with up to twice this dose of 2,3,7,8-TCDD in the soil from the manufacturing site. The limited data on 2,3,7,8-TCDD levels in the liver showed much higher levels following administration of recontaminated soil versus contaminated soil from the manufacturing site.

Umbreit et al. (1986a) thus demonstrated that gavaged 2,3,7,8-TCDD containing soil from the manufacturing site was substantially less toxic than equivalent doses of 2,3,7,8-TCDD in corn oil. However, quantitative comparison of the effective doses in this study is difficult. Approaches to a quantitative comparison are outlined below.

(1) Guinea pigs receiving 12 ug/kg 2,3,7,8-TCDD in contaminated soil experienced no deaths, while five out of eight guinea pigs receiving 6 ug/kg 2,3,7,8-TCDD in corn oil died, with no groups tested having lower doses in corn oil. Other authors have provided data on the toxic effects of 2,3,7,8-TCDD in corn oil which could aid in the comparison.

McConnell et al. (1984) observed one out of six animals dying at

1 ug/kg and six out of six animals dying at 3 ug/kg. Silkworth et al. (1982) observed three out of six animals dying at 2.5 ug/kg and no deaths out of six at 0.5 ug/kg. Comparing these data directly with the Umbreit et al. results would suggest that the 2,3,7,8-TCDD in the Newark manufacturing site soil was less effective, by a factor of 10 or greater, in producing toxicity than 2,3,7,8-TCDD in corn oil.

(2) Umbreit et al. reported a "slightly reduced" weight gain in guinea pigs receiving 6 ug/kg of 2,3,7,8-TCDD in Newark manufacturing site soil, and a "greater reduction" at the 12 ug/kg dose. No other signs of toxicity were noted in these groups. The animals receiving 6 ug/kg 2,3,7,8-TCDD in corn oil, in contrast, exhibited a marked loss of body weight and showed toxicity and mortality. Silkworth et al. (1982) also provided data on weights of guinea pigs receiving 2,3,7,8-TCDD in corn oil. Those receiving 2.5 ug/kg exhibited a marked reduction in weight gain among three out of six survivors, while those receiving 0.5 ug/kg showed a weight gain comparable to vehicle controls. Comparison of this weight data with that of Umbreit et al. suggests that the 2,3,7,8-TCDD in corn oil was more than 5 times but less than 25 times as potent as 2,3,7,8-TCDD in the Newark soil. This comparison assumes that the effect of the Newark manufacturing site soil on weight gain was due to 2,3,7,8-TCDD as opposed to other compounds in the soil. Numerous other dioxin and furan compounds and other chemicals have been identified in this soil (Umbreit et al., 1987a). It has not been established that 2,3,7,8-TCDD is the sole or prime source of toxicity in the soil.

(3) Umbreit et al. presented liver concentrations of 2,3,7,8-TCDD after death or sacrifice at 60 days following gavage. Much lower concentrations of 2,3,7,8-TCDD were found in the livers of animals receiving soil from the manufacturing site compared with those receiving the dose in corn oil. There are, however, two factors that limit the conclusions than can be drawn from this comparison.

First, the corn oil group experienced major toxicity and weight loss, particularly

complete loss of body fat. These changes may have affected the partitioning of 2,3,7,8-TCDD within the body, leading to a higher concentration in the livers of the animals experiencing toxicity. Second, the animals gavaged with corn oil died early--half were dead by 26 days, while all of the guinea pigs treated with soil survived to 60 days (with the exception of one gavage death). The U.S. EPA (1985c) reported a half-life for 2,3,7,8-TCDD elimination of 30 $\pm$ 6 or 22 to 43 days from two studies in guinea pigs. Additionally, the U.S. EPA (1985c) stated that elimination in the guinea pig may follow zero-order kinetics. Differences in elimination due to differences in periods of survival are likely to have affected the relative quantities of 2,3,7,8-TCDD found in the livers of the test groups.

Perhaps a more appropriate comparison can be made with the four animals receiving 0.32 ug/kg of 2,3,7,8-TCDD in contaminated soil from the Newark salvage site. These animals experienced no reported toxic signs (weight data not presented) and survived the full 60-day experiment. Approximately 6% of the gavage dose was found in the liver of these animals, while only about 0.06% of the gavage dose was found in the livers of guinea pigs in the 12 ug/kg group receiving the Newark manufacturing site soil. This would suggest that the 2,3,7,8-TCDD in the manufacturing site soil was 100 times less bioavailable. However, given the different doses used and the fact that only a single pooled sample was analyzed for 2,3,7,8-TCDD in each group, caution must be used in interpreting this comparison.

The 2,3,7,8-TCDD in soil from the salvage site was substantially bioavailable, based on the single liver tissue analysis. Approximately 6% of the administered dose was recovered from the livers of these animals at 60 days. This can be compared with data on hamsters given 2,3,7,8-TCDD in corn oil by McConnell et al. (1984), where approximately 8% of the 2,3,7,8-TCDD could be recovered in the 1 ug/kg dose group among survivors at 30 days.

McConnell et al. (1984) treated Hartley guinea pigs (2.5 weeks old) with single gavage doses of either 2,3,7,8-TCDD or dioxin contaminated soil from two sites in Missouri. The 2,3,7,8-TCDD concentrations from the two sites were reported at 700 and 880 ppb respectively; total tetrachlorodibenzofurans (TCDF) concentrations in the soil were 40 to 80 ppb, and polychlorinated biphenyls (PCB) concentrations were 3 to 4 ppm.

Taking into account the relative toxicities, the authors concluded that toxicity from the other compounds was likely to be small compared with that from 2,3,7,8-TCDD. Livers were analyzed for 2,3,7,8-TCDD at death or sacrifice at 30 days following treatment. Treatment deaths occurred between 5 and 21 days post-gavage.

Guinea pigs that died exhibited severe loss of body fat, markedly reduced thymus and testicle size, and adrenal hemorrhage. No adverse affects were noted in animals treated with decontaminated soil. For 2,3,7,8-TCDD in corn oil and for both contaminated soils, there were clear dose-responses in mortality. The calculated LD_{50} values for the two soil types were lower than the LD_{50} for 2,3,7,8-TCDD in corn oil by a factor of three to four.

There was a dose-response between the liver concentration of 2,3,7,8-TCDD and the gavage dose; the details of this relationship are complex. Animals dying during the experiment had liver concentrations a factor of 1.4 to 3.2 higher than animals in the same dose groups who survived 30 days. This observation makes quantification of the dose-response relationships difficult (all or most of the animals in the low-dose groups survived the experiment, while all of the animals in the high-dose groups died). When the liver concentrations of 2,3,7,8-TCDD in animals dying early at the middle and high-dose groups are compared, there appears to be a greater-than-linear increase in liver concentration with dose for the Times Beach and Minker Stout soil groups, with a 3.3-fold increase in dose producing a 10- to 13-fold increase in liver concentration.

Liver concentrations of animals in the different dosing groups can best be compared among groups that experienced similar mortality.

(1) Animals in dose groups in which all animals died within 30 days: 2,3,7,8-TCDD in corn oil, approximately 20% of the administered dose was in the liver. For the soil-treated groups, 13% and 11% of the doses, respectively, were in the liver. Comparison of these data suggest that 2,3,7,8-TCDD was approximately twice as available through corn oil as through soil.

(2) Animals surviving the 30-day experiment (in groups where at least 4 out of 6 survived): For 2,3,7,8-TCDD in corn oil, 7.5% of the administered dose was in the liver. For soil-treated animals < 3.6, 1.3, < 4.2, and 2.0% of the doses, respectively, were in the liver. Comparison here would suggest

that 2,3,7,8-TCDD was approximately four times as available through corn oil as through soil.

The authors note that the differences in liver concentrations observed in the study may reflect varying partitioning of the 2,3,7,8-TCDD among internal organs, since dying animals suffered major loss of body weight and fat content. In addition, surviving animals would have had greater opportunity to metabolize and excrete 2,3,7,8-TCDD due to a longer lifetime.

Umbreit et al. (1986a) reported additional chemical analyses of the Times Beach soil. Soxhlet extraction of the Times Beach soil yielded a similar quantity of 2,3,7,8-TCDD to the solvent extraction reported by McConnell et al. (1984). This is in contrast to the Newark manufacturing site soil used in the Umbreit et al. (1987a) experiments, where only a small fraction of soxhlet-extractable 2,3,7,8-TCDD was extractable by the solvent extraction methodology used by McConnell et al. (1984).

McConnell et al. (1984) also reported an experiment in which groups of six Sprague-Dawley rats were given single gavage doses of 2,3,7,8-TCDD in corn oil or dioxin-contaminated soil from the Minker site. Induction of aryl hydrocarbon hydroxylase (AHH) in the rat livers was measured at sacrifice 6 days after dosing. Experimental doses ranged from 0.4 to 5.0 ug/kg 2,3,7,8-TCDD. Measured AHH induction was similar for groups receiving 2,3,7,8-TCDD in corn oil or receiving contaminated soil containing nearly equal doses of 2,3,7,8-TCDD. For example (based on the rate of formation of 3-hydroxybenzo[a]pyrene), AHH activity was measured at 1,269 pmole min^{-1} mg^{-1} for the group receiving 5 ug/kg 2,3,7,8-TCDD in corn oil and at 1,230 pmole min^{-1} mg^{-1} for the group receiving 5.5 ug/kg 2,3,7,8-TCDD in contaminated soil. For the five dose groups, the AHH activity for the soil group ranged from 50% to 110% of the activity in the corn oil group.

The McConnell et al. (1984) rat data indicate that the bioavailability of 2,3,7,8-TCDD from the Minker site soil was at least 50% of that of equivalent doses of 2,3,7,8-TCDD in corn oil.

Lucier et al. (1986) provided additional information on the induction of hepatic enzymes in rats by the 2,3,7,8-TCDD contaminated soil from the Minker site tested by McConnell et al. (1984). AHH induction was similar for the groups of rats receiving

2,3,7,8-TCDD in corn oil and contaminated soil (within a factor of two) over a broader range of doses (0.015 ug/kg to 5 ug/kg) than reported by McConnell et al. (1984). In a second enzyme assay using the same animals, UDP glucuronyltransferase activity was found to be slightly higher in groups receiving 2,3,7,8-TCDD in corn oil than groups receiving equal doses in contaminated soil.

Liver concentrations of 2,3,7,8-TCDD for the rats were also reported. For the corn oil vehicle the liver concentrations were 40.8 $\pm$ 6.5 ppb at the 5 ug/kg dose and 7.6 $\pm$ 2.5 ppb at the 1 ug/kg dose. Assuming that the liver comprises 4.0% of body weight, the retention rates for the 5 and 1 ug/kg doses were 33% and 30%, respectively. In rats receiving 2,3,7,8-TCDD in contaminated soil, the 5.5 ug/kg group had liver concentrations of 20.3 $\pm$ 12.9 ppb, and the 1.1 ug/kg group had concentrations of 1.8 $\pm$ 0.3. Thus, retention rates for the 5.5 and 1.1 ug/kg groups are estimated at 14% and 7%, respectively. These data indicate that liver retention in the soil group was 20% to 40% of that in the corn oil vehicle groups.

Umbreit et al (1986b) report additional studies of mortality in guinea pigs treated with soil containing 2,3,7,8-TCDD from Newark (manufacturing site) and Missouri (Times Beach) previously tested by Umbreit et al (1985, 1986a) and McConnell et al. (1984), respectively. Guinea pigs received a single gavage dose of a soil suspension and were observed for 60 days. After autopsy, deaths were classified as whether or not they appeared to be due to TCDD toxicity. Substantial mortality (25% overall) from conditions not attributed to TCDD was observed across all groups.

The data for both the Newark and Missouri sites are similar in trend for the previous data on these sites; and clearly indicate the greater toxicity of the Newark soil for given equal administered doses of 2,3,7,8-TCDD. With larger groups of guinea pig studied, a toxicity-related death was observed in both the 5 and 10 mg/kg dose groups for Newark soil while no deaths were observed in corresponding dose groups (6 and 12 mg/kg) with fewer animals in Umbreit et al. (1986a).

Comparing groups within this study, similar mortality (1 or 2 deaths in 10 to 16 animals) was seen in both the 5 and 10 ug/kg Newark groups and the 1 and 3 ug/kg Missouri groups. These results suggest that the toxicity of these materials differs by an order of magnitude or less. As noted above, the degree to which toxicity from these soils

can be attributed to 2,3,7,8-TCDD in the presence of numerous other related toxic compounds is not known. 2,3,7,8-TCDD tissue concentrations were not reported in this work.

In another comparative study Umbreit et al. (1987b) compared the Newark manufacturing site and Times Beach soils in the induction of aryl hydrocarbon hydroxylase (AHH) in rats. While the use of only single dose levels prevents detailed analysis, the two soils proved quite similar in their ability to induce AHH. The explanation for the difference in this finding from those observed in the toxicity studies discussed above is not clear, but may relate to the presence of other toxic and/or AHH inducing compounds.

Umbreit et al. (1987a) report a reproductive toxicity study with soils from the Newark manufacturing site and salvage yard previously studied by Umbreit et al. (1986a). Female mice were treated thrice weekly with soil from these sites, with treatment continuing through fertilization to weaning of pups. The total doses of 2,3,7,8-TCDD received by the mice were 720 ug/kg in manufacturing site soil, and 86 ug/kg in salvage yard soil. A corn oil vehicle group and a recontaminated soil group received a total of 225 ug/kg.

Deaths in animals showing "classic signs" of TCDD toxicity were observed in the corn oil and recontaminated soil groups, and indicate appreciable bioavailability of 2,3,7,8-TCDD. Deaths were also observed in animals receiving manufacturing site soil but the authors did not observe "classic signs" of TCDD toxicity. Fewer live pups born and fewer pups surviving until weaning were observed in the manufacturing site soil group compared with those receiving decontaminated soil. TCDD completely blocked reproduction in the corn oil and recontaminated soil groups. The results of this study demonstrate acute and reproductive effects occurred in animals receiving manufacturing site soil. However, these effects were of a lesser magnitude than those seen in animals treated with 2,3,7,8-TCDD in corn oil at a dose three fold lower. The authors note the presence of substantial quantities of other toxic substances in the manufacturing site soil (chemical analyses presented). No toxic effects were noted in animals treated with salvage site soil, who received a much smaller 2,3,7,8-TCDD dose. The data does not allow a quantitative evaluation of the bioavailability of 2,3,7,8-TCDD.

Kaminski et al. (1985) and Silkworth et al. (1982) reported the results of a series of

studies on the toxicity of soot containing dioxin and furan compounds from a fire involving transformer fluid containing PCBs. Hartley guinea pigs (500 to 600 g) received single oral doses of soot in an aqueous vehicle, a soxhlet extract of the soot in the same vehicle, or 2,3,7,8-TCDD in either an aqueous vehicle or corn oil.

The soot was reported to contain 2.8 to 2.9 ppm 2,3,7,8-TCDD and 124 to 273 ppm 2,3,7,8-TCDF. The total polychlorinated dibenzofuran content was estimated at 5,000 ppm. Animal weights and mortality were recorded for 42 days, at which point the survivors were sacrificed and LD_{50} values were calculated. Blood chemistry and a pathologic examination were performed at sacrifice.

Silkworth et al. (1982) noted that the LD_{50}s for contaminated soot and soot extract were similar at 410 and 327 equivalent ug/kg, indicating that the matrix had only a small effect on toxicity. If expressed in terms of the content of 2,3,7,8-TCDD, the LD_{50} from soot is 2.5 ug/kg, which is a factor of seven below the LD_{50} for 2,3,7,8-TCDD in an aqueous vehicle, suggesting that other compounds contributed to the toxicity of the soot and soot extract.

The authors stated that they adopted an aqueous vehicle in these experiments because it was nontoxic and provided a stable suspension of soot; they regarded this vehicle as more appropriate for modeling of human exposure conditions than an oil vehicle. The data from these experiments also demonstrate that use of an oil vehicle leads to substantially greater 2,3,7,8-TCDD toxicity than does an aqueous vehicle.

Comparison of mortality and weight loss in groups of female guinea pigs receiving 500 ug/kg of soot or the equivalent amount of soot extract suggests that the extract may be somewhat more toxic; however, all six animals died in the 1,000 ug/kg soot group, while four out of five died in the 500 ug/kg extract group. Taken together, these data indicate that the soxhlet extract of soot in an aqueous vehicle was between one and two times as toxic as the soot itself. It is likely that a larger difference in toxicity would have been observed if the soot extract was in an oil vehicle.

Van den Berg et al. (1983) fed small groups of male Wistar rats fly ash from a municipal incinerator (pretreated with HCl) containing dioxins and furans, a soxhlet extract of the fly ash, or a purified extract of the ash that was obtained using column chromatography. 2,3,7,8-TCDD was present as 3.3% of the TCDD isomer group in the

fly ash extract. (The authors did not specify whether this reference was to crude or purified extract.) 2,3,7,8-TCDF was present as 17.9% of the tetra-CDF isomer group in the extract. The rats were fed 2 g/d fly ash mixed with diet or the residual from 2 mL/d extract after the extract was mixed with diet and the solvent was evaporated. The animals were exposed to the treated diet for 19 days, and then sacrificed, and the liver tissue was analyzed for the presence of dioxins and furans.

Approximately 1% of the 2,3,7,8-TCDD dose from fly ash was retained in the liver, and approximately 4% of the dose of this isomer from fly ash extract was so retained. The corresponding percentages for 2,3,7,8-TCDF are 0.3 and 1.0. Data on the retention of isomer groups in adipose tissue were presented for the extract-treated groups but not for the fly ash-treated group. The concentrations of the various isomers in adipose tissue are comparable to, or less than, the concentrations in liver tissue.

The U.S. EPA (1985b) reported a half-life for elimination of 2,3,7,8-TCDD in the rat of 20 days at high dose. If a similar half-life is assumed in this experiment, the quantities of 2,3,7,8-TCDD in the animals at the end of the 19-day feeding experiment would be significantly less than the absorbed dose, but still of the same order of magnitude. However, the recovery percentages in this study are low for both the fly ash and fly ash extract groups in comparison with other studies in which 2,3,7,8-TCDD was administered to rats. Fries and Marrow (1975) fed rats diets containing 7 or 20 ppb of 2,3,7,8-TCDD for a period of up to 42 days. After 14 days of feeding, the rat livers contained an average of 32% of the cumulative administered dose; at 28 days, 21% of the dose; and at 42 days, 18% of the dose. Thus, in the van den Berg et al. (1983) study, the liver retention of 2,3,7,8-TCDD for the fly ash extract group is a factor of five to eight below what could be anticipated for the Fries and Marrow (1975) data, and the liver retention in the van den Berg et al. (1983) group fed soot is a factor of 20 to 30 lower than that seen by Fries and Marrow (1975). Data from Kociba et al. (1976), Rose et al. (1976), and Kociba et al. (1978) lead to similar conclusions to those from the Fries and Marrow (1975) data regarding the fraction of cumulative 2,3,7,8-TCDD dose retained in the rat liver.

An explanation of the low level of recovery for the animals receiving the soxhlet extract of soot is not apparent. It is possible that the presence of multiple compounds affected absorption or metabolism in the rats fed soot and soot extract.

A second approach to the van den Berg et al. (1983) data is to compare the ratios of liver concentrations for dioxins in fly-ash-treated animals to the concentrations in extract-treated animals. These ratios, based on measurements in small numbers of animals, indicate a substantial bioavailability of dioxin and furan compounds from the tested fly ash. This availability varied among the different isomers with the value of 0.3 for 2,3,7,8-TCDD, indicating that this isomer was three times as available from fly ash extract as from fly ash.

Van den Berg et al. (1985) fed fly ash (pre-treated with HCl) to Wistar rats, guinea pigs, and Syrian golden hamsters. Fly ash was mixed with standard laboratory diet at 2.5% by weight, and animals were allowed to eat ad libitum. The amount of fly ash consumed by each group of five rodents was determined by the authors. For each species there were three groups of animals each fed fly ash for approximately 32 days (group I), 60 days (group II), or 94 days (group III). Concentrations of dioxin and furan isomer groups in the food were presented, and include 1.4 ng/g TCDD compounds and 2.1 ng/g TCDF compounds.

The authors presented calculated recovery percentages for the cumulative dose of specific isomers in the rodent liver. For 2,3,7,8-TCDD in guinea pigs, 3.7%, 0.9%, and 1.4% of the administered dose was recovered in the liver in groups I, II, and III, respectively. The 32-day (group I) recovery percentage is somewhat higher than seen in the lower dose groups receiving 2,3,7,8-TCDD contaminated soil in McConnell et al. (1984). The value in hamsters was approximately 2% (only reported for group II), and analytical problems prevented this determination in rats. No other TCDD compounds were quantified. Similarly, for 2,3,7,8-TCDF, guinea pigs showed retention of 4.7%, 2.2%, 2.5% of the administered dose in groups I, II, and III, respectively. For both 2,3,7,8-TCDD and 2,3,7,8-TCDF the recovery percentages in guinea pigs at 32 days were approximately a factor of 4 to 15 higher than that observed in the van den Berg et al. (1983) study in rats.

Other TCDD compounds that were present showed comparable or somewhat lower retention, averaging 1% to 2% over the animals groups. No TCDD or TCDF compounds were detected in hamster liver or analyzed for in rat liver. Higher chlorinated congeners most typically showed retention in the range of 2% to 5% in rat liver and 1% to 3% in

guinea pig liver, with the exception of 2,3,4,7,8-PeCDF (9.8%, 8.3%, and 11.3% in the hamster groups). Few other compounds were found in hamster liver, but 2,3,4,7,8-PeCDF was found with a recovery of 5% to 8% and 2,3,4,7,8-HxCDD was found at 3% to 7%.

As with other experiments in which the retention of dioxins in the liver has been determined, these percentages place a lower bound on the bioavailability of the dioxins but, because not all dioxin is localized in the liver, do not permit bioavailability to be estimated without knowledge of the elimination of the administered dose over time and the quantity of dioxins in the remainder of the organism. No positive control group receiving 2,3,7,8-TCDD was included for comparison.

Poiger and Schlatter (1980) conducted several experiments in Sprague-Dawley rats (180 to 220 g) in which liver concentrations of tritium label from 2,3,7,8-TCDD were determined using various doses and vehicles. All experiments consisted of a single gastric intubation of 2,3,7,8-TCDD-containing material, followed by animal sacrifice at predetermined times. The doses used were well below the LD_{50} in the rat (the maximum dose applied was 5 ug/kg), and no deaths or toxic effects were reported.

In a preliminary experiment, rats were treated with 14.7 ng/rat 2,3,7,8-TCDD in ethanol. The results indicate substantial localization of 2,3,7,8-TCDD in the rat liver, with a decrease of a factor of two in the fraction of the dose in the liver between 1 and 4 days. Poiger and Schlatter (1980) conducted all further studies with sacrifice at 24 hours to maximize the recovery of 2,3,7,8-TCDD from the liver.

In a second experiment, the authors administered 2,3,7,8-TCDD doses in ethanol ranging from 15 to 1,070 ng/rat to groups of six rats. They found a graded increase in percentage retained in the liver from 37% $\pm$ 1% at the 15 ng dose to 51% $\pm$ 4% at 280 ng. At the high-dose point, the percentage may have fallen (42% $\pm$ 10% at 1,070 ng).

In a further experiment, 2,3,7,8-TCDD was administered at low dose in a series of vehicles. These data demonstrate that administration of 2,3,7,8-TCDD in soil reduced the retention of the dose in the liver to 66%, or 44% of the retention seen with 2,3,7,8-TCDD in ethanol. The lower value, 44%, was obtained for soil that was aged for 8 days at 30-40 °C following addition of 2,3,7,8-TCDD. This observation is consistent with the findings of other studies reported here that 2,3,7,8-TCDD from environmental soil (naturally aged) was generally less available than 2,3,7,8-TCDD freshly added to clean

samples of these soils. The aqueous suspension of 2,3,7,8-TCDD in activated carbon showed little evidence of bioavailability; this is supported by the authors' measurements showing that 2,3,7,8-TCDD was only slightly extractable from the activated carbon matrix by various solvents. In contrast, 58% to 70% of 2,3,7,8-TCDD could be recovered from soil samples by washing with hexane/acetone (4:1 v/v).

Poiger and Schlatter (1980) also presented results from several skin application experiments with TCDD-containing materials using rats and rabbits (not reviewed here).

Bonaccorsi et al. (1984) reported the results of a study of gut absorption of 2,3,7,8-TCDD from soil taken from the Seveso, Italy accident site. Soil containing 81 $\pm$ 8 ppb 2,3,7,8-TCDD from the "highly contaminated" area in Seveso was administered to albino male rabbits (2.6 $\pm$ 0.3 kg) in daily gavage doses for seven days. Additional samples of clean soil were spiked with 2,3,7,8-TCDD in the laboratory to yield 10 and 40 ppb contamination levels and were administered to rabbits following the same protocol. For comparison, rabbits were also treated with 2,3,7,8-TCDD in solution in acetone-vegetable oil (1:6) or alcohol-water (1:1). Rabbits were sacrificed on the day after treatment stopped and liver concentrations of 2,3,7,8-TCDD were measured. The authors did not remark on the presence or absence of toxicity in the treated rabbits. EPA (1985a) reports values for the single dose LD_{50} of 2,3,7,8-TCDD in rabbits of 115 and 275 ug/kg. The total doses received by the rabbits in this study were approximately 54, 107, and 215 ug/kg over seven days. Based on this comparison, there is a likelihood that toxic effects occurred in the Bonaccorsi work, and as noted above, toxicity has the potential to affect the tissue concentrations of 2,3,7,8-TCDD. For this reason, the most appropriate comparisons among these data are between groups showing similar liver concentrations of 2,3,7,8-TCDD, which may then be inferred to have experienced similar toxic effects.

That this method of comparison is desirable can also be seen from the Bonaccorsi et al. (1984) data, where both solvent vehicle groups and the spiked soil groups show an increase of the fraction of the dose in the liver at the higher administered doses. However, it should be mentioned that use of two different solvent vehicles complicates interpretation. Similar liver concentrations of 2,3,7,8-TCDD were seen in the 40 ug/d solvent vehicle and 80 ug/d Seveso soil groups. Comparing the percentage of liver retention in these two groups indicates absorption from Seveso soil was 40% of that from

the solvent vehicle. Using the same approach, comparison of the 80 ug/d solvent vehicle and 160 ug/d Seveso soil groups indicates that absorption from the soil was 41% of that from the solvent.

The same approach can be used to compare absorption from the solvent vehicle and from the spiked soil. In this case the 40 ug/d solvent vehicle group had the liver concentrations closest to either the 40 or 80 ug/d spiked soil groups. Comparison of the percentage of dose in the liver indicates absorption from spiked soil is 68-73% of that from the solvent vehicle. Bonaccorsi et al. (1984) conducted work with either aged or non-aged spiked soil but do not present data to allow a comparison of these groups.

Shu et al. (1987, as cited by Leung and Paustenbach, 1987) studied 2,3,7,8-TCDD from the Missouri site tested by McConnell et al. (1984). Their paper reports an oral bioavailability of approximately 43% in the rat dosed with environmentally contaminated soil from Times Beach, Missouri. This figure did not change significantly over a 500-fold dose range of 2 to 1450 ng 2,3,7,8-TCDD per kg of body weight for soil contaminated with approximately 2, 30 or 60 ppb of 2,3,7,8-TCDD. The data from this study is not now available to the Exposure Assessment Group of EPA for review.

C.2 Summary of Bioavailability

Table C-1 summarizes data that are pertinent to the bioavailability of 2,3,7,8-TCDD from environmental matrices. Studies of bioavailability, which examined soil samples, soot, and fly ash, have utilized three methodologies: measuring acute toxicity, retention of 2,3,7,8-TCDD in the liver, and induction of hepatic enzymes.

Among the five samples of soil from contaminated sites that have been tested, three have shown substantial bioavailability, e.g., 25% to 50%, when compared with 2,3,7,8-TCDD in corn oil gavage. A fourth soil sample was compared with 2,3,7,8-TCDD administered in a solvent vehicle, and fell in this range. The fifth soil, tested by Umbreit et al. (1986a,b; 1987a,b) showed bioavailability substantially less than the other soils tested. While difficult to gauge quantitatively, dioxin from this fifth soil may be an order of magnitude less available than from the other soils.

Additionally, three samples of soil spiked with 2,3,7,8-TCDD have been tested for bioavailability, including one sample in which the 2,3,7,8-TCDD was incubated with soil at

Table C-1. Summary of Data on the Bioavailability of 2,3,7,8-TCDD Following Ingestion of Environmental Matrices

Reference	Matrix/Source	Species	Dosing	Observation
Umbreit et al. (1986a,b)	Soil/Newark Manuf. Site	Guinea pig	Single gavage	2,3,7,8-TCDD in soil <10% as toxic as in corn oil, based on lethality and weight loss. 2,3,7,8-TCDD in the manuf. site soil had retention in liver approx. 1% as great as with salvage site soil.
Umbreit et al. (1986a,b)	Soil/Newark Salvage Site	Guinea pig	Single gavage	Liver retention similar to 2,3,7,8-TCDD in corn oil from lower dose McConnell et al. (1984) data. Toxicity similar to equal dose of 2,3,7,8-TCDD in corn oil.
	Recontaminated Soil	Guinea pig	Single gavage	
McConnell et al. (1984)	Soil/Times Beach, MO	Guinea pig	Single gavage	LD_{50} data indicate 2,3,7,8-TCDD in soil approx. 25% as toxic as in corn oil. Comparing animals dying early, liver retention of 2,3,7,8-TCDD in soil group approx. 50% of that in corn oil vehicle group. Comparing animals surviving experiment, liver retention of 2,3,7,8-TCDD in soil group approx. 20% of that in corn oil vehicle group.

Table C-1 (continued)

Reference	Matrix/Source	Species	Dosing	Observation
McConnell et al. (1984)	Soil/Minker Site, MO	Guinea pig	Single gavage	LD_{50} data indicate soil approx. 30% as toxic as 2,3,7,8-TCDD in corn oil. Comparing animals dying early, liver retention approx. 50% of that in corn oil vehicle group. Comparing animals surviving experiment, liver retention approx. 25% of that of corn oil vehicle group.
McConnell et al. (1984) and Lucier et al. (1986)	Soil/Minker Site, MO	Rat	Single gavage	Introduction of AHH and UDP glucuronyltransferase activity > 50% of that in groups receiving 2,3,7,8-TCDD in corn oil. Liver retention 20-40% of that in rats receiving equal dose of 2,3,7,8-TCDD in corn oil.
Poiger and Schlatter (1980)	Soil with 2,3,7,8-TCDD			Liver retention approx. 40-70% of that in ethanol vehicle groups.
Bonaccorsi (cited in McConnell et al., 1984)	Soil/Seveso Accident Site	Rabbit		2,3,7,8-TCDD 30% as bioavailable from soil as from solvent vehicle.

Table C-1 (continued)

Reference	Matrix/Source	Species	Dosing	Observation
Kaminski et al. (1985) and Silkworth et al. (1982)	Soot from fire	Guinea pig	Single gavage	LD_{50} data indicate soot containing dioxins and furans approx. equal in toxicity to soxhlet extract of soot in aqueous vehicle.
van den Berg et al. (1983)	Incinerator Fly ash	Rat	19 day feeding	Liver retention of 2,3,7,8-TCDD from ash and ash extract 1% and 4% respectively,, indicating 2,3,7,8-TCDD approx. 25% as available from ash as from extract. Both ash and extract retentions are low compared with other feeding and gavage studies.
van den Berg et al. (1985)	Incinerator fly ash	Guinea pig	Feeding	4%, 1% and 1% retention of total dose in liver following feeding for 32, 60, and 94 days, respectively.
van den Berg et al. (1985)	Incinerator fly ash	Hamster	60 day feeding	2% of total dose retained in liver following feeding.
Poiger and Schlatter (1980)	2,3,7,8-TCDD on activated carbon	Rat	Single gavage	<0.1% retention in liver.

an elevated temperature. The 2,3,7,8-TCDD added to these soil samples proved to be highly available (e.g., 40% to 70%).

In one study, soot from a transformer fire containing dioxins and furans proved similarly toxic to a soxhlet extract of the soot in an aqueous vehicle. However, the soot extract may have proved more toxic if delivered in corn oil, as was 2,3,7,8-TCDD in the soil studies. The availability of 2,3,7,8-TCDD and other dioxins and furans from incinerator fly ash have been addressed by van den Berg et al. (1983, 1985) in extended feeding studies. In these studies, liver retention of 2,3,7,8-TCDD from either fly ash or fly ash extract proved low, with availability from fly ash being approximately 25% of that from the extract.

The individual studies reviewed have a variety of limitations, as discussed in the preceding text. A notable limitation was that some experiments were conducted using highly toxic doses of 2,3,7,8-TCDD, so that determination of bioavailability was complicated by wasting and early death of the test animals. It should also be noted that, while the relative retention of 2,3,7,8-TCDD in the liver can serve as an appropriate indication of differences in bioavailability between samples, the percentage of dose found in the liver only places a lower bound on absorption. This is particularly relevant to experiments where animals have been maintained for many weeks after dosing and an undetermined quantity of 2,3,7,8-TCDD has been excreted.

Finally, toxicity data for mixtures for which both toxicity and bioavailability of individual compounds may vary are difficult to interpret quantitatively in terms of bioavailability.

As presented in U.S. EPA (1985c), Rose et al. (1976) determined gut absorption of 2,3,7,8-TCDD in a 1:25 mixture of acetone to corn oil (by volume) in the rat. In both single dose and multiple dose experiments, measured absorption was approximately 85%. Assuming that absorption from pure corn oil is similar to that from this mixture, and assuming that absorption in other species for which data are not available is similar, the 85% factor can be applied to the data presented here to obtain an approximate range for typical 2,3,7,8-TCDD absorption from soil. Using this factor, the estimated relative bioavailability of 2,3,7,8-TCDD from soil is 25% to 50% and, when compared with corn oil, provides an estimate of gut absorption of 20% to 40% of ingested 2,3,7,8-TCDD in

soil. This estimate is comparable with the 20% to 26% absorption from 2,3,7,8-TCDD treated soil from the work of Poiger and Schlatter (1980).

Recognizing these limitations, the weight of evidence indicates that 2,3,7,8-TCDD is often highly available from environmental materials. However, in one tested soil sample the compound was substantially less bioavailable. While the data are too sparse to allow a prediction as to whether a particular environmental sample will prove more or less bioavailable, one important suggestion has emerged. In the two samples that have proved least bioavailable (the Umbreit et al. (1986a) manufacturing site soil sample, and 2,3,7,8-TCDD on activated carbon tested by Poiger and Schlatter (1980)) the 2,3,7,8-TCDD was largely resistant to solvent extraction. This was not the case for more bioavailable materials.

Further research, using short-term experiments in which animals are handled under identical conditions and are fed dioxins in different media, is needed for an improved comparison of absorption between different environmental samples. Acutely toxic doses should be avoided to ensure that tissue concentrations are directly interpretable. Experiments studying both tissue retention and enzyme induction should prove valuable for this research. Whole-body levels of 2,3,7,8-TCDD need to be related to liver concentrations, and the effects of metabolism need to be addressed. The vehicle of administration has been shown to affect acute 2,3,7,8-TCDD toxicity, and vehicle effects need to be considered in designing experiments.

C.3 Distribution

Ryan et al. (1985) examined the distribution of 2,3,7,8-TCDD in two humans at autopsy. On a weight basis, there were 6 ppt of TCDD in fat, 2 ppt in liver and below levels of detection in kidney and muscle. They reported that on a per lipid basis the levels were similar between tissues. It is important to note that one of these subjects suffered from a fatty liver syndrome, possibly resulting in higher levels in the liver than might normally be found in healthy individuals.

Poiger and Schlatter (1986) estimated that about 90% of the total body burden of 2,3,7,8-TCDD was sequestered in fat. Levels of 2,3,7,8-TCDD averaging 5-10 ppt have been reported for background populations in St. Louis, MO, by Graham et al. (1986), and

in Atlanta, GA, and Utah by Patterson et al. (1986). These data are consistent with the lipid bioconcentrations assumptions made in calculations of daily intakes (*vidae supra*).

Patterson et al. (1987) developed a high resolution gas chromatographic/high resolution mass spectrometric analysis for 2,3,7,8-TCDD in human serum. A high correlation was reported between adipose tissue and serum concentrations when adjusted for total lipid content. The reader is referred to other documents (U.S/ EPA, 1993; Schlatter, 1991; Schecter, 1991) for more details on the distribution and elimination.

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