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Update to An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000

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ABSTRACT

The purpose of this document is to present an update and revision to the dioxin source inventory published in 2006 (U.S. EPA, 2006), which is an inventory of sources and environmental releases of dioxin-like compounds in the United States. The current document presents updated estimates of environmental releases of dioxin-like compounds to the air, water, land and products. The sources are grouped into five broad categories: combustion sources, metals smelting/refining, chemical manufacturing, natural sources, and environmental reservoirs. Estimates of annual releases to land, air, and water are presented for reference years 1987, 1995, and 2000 (the years presented in the original report). The quantitative results are expressed in terms of the toxicity equivalence (TEQ) of the mixture of polychlorinated dibenzo-*p*-dioxin (CDD) and polychlorinated dibenzofuran (CDF) compounds present in environmental releases using a procedure sanctioned by the World Health Organization (WHO) in 1998. This TEQ procedure translates the complex mixture of CDDs and CDFs characteristic of environmental releases into an equivalent toxicity concentration of 2,3,7,8-tetrachorodibenzo-p-dioxin (2,3,7,8-TCDD), the most toxic member of this class of compounds. The total releases under the national inventory for 1987 in g WHO_{98} TEQ_{DF} were 15,000 to air, 2,400 to land, 360 to water, and 36 to products. For 1995, the releases in g WHO_{98} TEQ_{DF} were 3,400 to air, 2,500 to land, 30 to water, and 47 to products. For 2000, the releases in g WHO_{98} TEQ_{DF} were 2,300 to air, 2,300 to land, 28 to water, and 7 to products. While the overall decreasing trend in emissions seen in the original report continues, the individual dioxin releases in this draft updated report are generally higher than the values reported in 2006. This is largely due to the inclusion (in all three years) of additional sources in the quantitative inventory that were not included in the 2006 report.

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LIST OF ABBREVIATIONS AND ACRONYMS

APCD	Air pollution control device
BDDs	polybrominated dibenzo-*p*-dioxins
BDFs	polybrominated dibenzofurans
Btu	British thermal unit
CARB	California Air Resources Board
CDD	polychlorinated dibenzo-*p*-dioxin
CDF	polychlorinated dibenzofuran
CFR	Code of Federal Regulations
CKD	cement kiln dust
DBF	dibenzofuran
DCBz	dichlorobenzene
DCI	data call-in
DCP	dichlorophenol
DL	detection limit
dscm	dry standard cubic meter
DSI	dry sorbent injection
EDC	ethylene dichloride
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	electrostatic precipitator
FF	fabric filter
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GAC	granular activated carbon
GC/ECD	gas chromatography/electron capture detector
GC/MS	gas chromatography/mass spectrometry
HCl	hydrogen chloride
HCBz	hexachlorobenzene
HDD	halogenated dibenzo-*p*-dioxin
HDF	halogenated dibenzofuran
HWI	hazardous waste incinerator
HxCB	hexachlorobiphenyl
IUPAC	International Union of Pure and Applied Chemistry

LOQ	limit of quantitation
MB-WW	mass burn waterwall
MCBz	monochlorobenzene
MMT	million metric tons
MSW	municipal solid waste
MT	metric ton (1000 kg)
MWI	medical waste incinerator
NCASI	National Council of the Paper Industry for Air and Stream Improvement
Nm^3	standard cubic meter
NMOC	nonmethane organic compound
OAQPS	Office of Air Quality Planning and Standards
OH	hydroxide ion
OPP	Office of Pesticide Programs
ORD	Office of Research and Development
OSW	Office of Solid Waste
PCA	Portland Cement Association
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PeCB	pentachlorobiphenyl
PeCBz	pentachlorobenzene
PM	particulate matter
POTW	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
ppmv	parts per million (volume basis)
ppt	parts per trillion
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RDF	refuse-derived fuel
SIC	Standard Industrial Classification
SIP	State Implementation Plan
TCBz	trichlorobenzene
TCDD	2,3,7,8-tetrachlorobidenzo-*p*-dioxin
TCDF	2,3,.7,8-tetrachlorobidenzofuran
TeCB	tetrachlorobiphenyl

TeCP	tetrachlorophenol
TEF	toxicity equivalency factor
TEQ	toxicity equivalence
TEQ/yr	toxicity equivalents per year
TrCB	trichlorobiphenyl
TrCP	trichlorophenol
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DCP	2,4-dichlorophenol
2,4,5-T	2,4,5-trichlorophenoxy (phenoxy herbicides)
U.K.	United Kingdom
USDA	U.S. Department of Agriculture
VCM	vinyl chloride monomer
WHO	World Health Organization
WS	wet scrubber

PREFACE

In 2006, EPA released a Dioxin Inventory Report that provided a comprehensive inventory and overview of sources and environmental releases of dioxin-like compounds in the United States (U.S. EPA, 2006). The purpose of this current document is to present an update and revision to the 2006 dioxin source inventory. This report includes some new data and also addresses additional comments EPA received on the 2006 Dioxin Inventory Report after it was published. This document was prepared by the National Center for Environmental Assessment, Office of Research and Development of the U.S. Environmental Protection Agency.

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EXECUTIVE SUMMARY

Synopsis

The purpose of this document is to present an update and revision to the dioxin source inventory published in 2006 (U.S. EPA, 2006), which is an inventory of sources and environmental releases of dioxin-like compounds in the United States for the years 1987, 1995, and 2000. The current document presents updated estimates of environmental releases of dioxin-like compounds to the air, water, land and products. These updates do not expand the scope of the document beyond the three reference years covered in the original document: 1987, 1995, and 2000.

The sources in this report are grouped into five broad categories: combustion sources, metals smelting/refining, chemical manufacturing, natural sources, and environmental reservoirs. The quantitative results are expressed in terms of the toxicity equivalence (TEQ) of the mixture of polychlorinated dibenzo-p-dioxin (CDD) and polychlorinated dibenzofuran (CDF) compounds present in environmental releases using a procedure sanctioned by the World Health Organization (WHO) in 1998. This TEQ procedure translates the complex mixture of CDDs and CDFs in the environmental releases into a single equivalent toxicity concentration (or mass) of 2,3,7,8-tetrachorodibenzo-p-dioxin (2,3,7,8-TCDD), the most toxic member of this class of compounds.

The updated releases to land and air are presented in Table ES-1, alongside the results from the 2006 report. The quantitative releases to water and products did not change.

While the overall decreasing trend in emissions seen in the original report continues, the individual dioxin releases in this draft updated report are generally higher than the values reported in 2006. This is largely due to the inclusion of additional sources in the quantitative inventory that were not included in the 2006 report.

Table ES-1. Overview of changes to total quantities of TEQ emissions to air and land from the 2006 inventory

Description	2006 Report	Present Report
Air Releases (g WHO_{98} TEQ)		
1987	13,500	15,000
1995	3,200	3,400
2000	1,300	2,300
Land Releases (g WHO_{98} TEQ)		
1987	130	2,400
1995	150	2,500
2000	82	2,300

For example, air releases are higher than listed in the 2006 report because the draft updated report includes emissions from forest fires as well as adjustments to emission factors used for municipal and medical waste incinerators. Forest fires were only reported as preliminary in 2006, but new experimental data has resulted in more certainty in the development of an emission factor for this source. Hence emissions were more accurately quantified as compared to the preliminary estimate made in 2006 and reclassified for inclusion in the quantitative inventory. The quantitative releases to land are markedly higher for all years compared to the 2006 report, due almost entirely to including ash from backyard trash burning in the current draft.

The current report still contains estimates for some sources that are considered preliminary and not included in the quantitative inventory. Some of these sources are potentially large and, if confirmed, could change the trend observations based on the currently quantified sources, as happened with forest fires for this updated report.

Approach

Dioxin releases from a source can be in the form of products, air emissions, water discharges, and solid residues. Solid residues can be used in products or disposed via landfills or incinerators. Each source addressed in this document is evaluated in terms of all of these outputs. However, not all of the outputs are considered to be environmental releases. Outputs judged to have a reasonable likelihood for releases to the circulating environment include all air emissions, water discharges, and landfarmed wastes. Outputs that are not generally considered environmental releases include waste disposal at a lined landfill and intermediate products or internal waste streams. While it is recognized that some of the dioxins contained in products or disposed in secure landfills may be released to the circulating environment at some time in the future, they are less likely to be released to the circulating environment during the same year that they entered into commerce or were landfilled. Consequently, these contained dioxins would not initially be considered environmental releases. Ideally, releases derived from products and landfill practices of past years would be included in the inventory for the reference year in which the releases occur. Unfortunately, the current state of science does not support estimating when and to what degree such releases may occur. For informational purposes, and when sufficient information is available, this document provides estimates of the amounts of solid waste disposed in landfills.

Sources can be categorized in terms of when releases occur: (1) contemporary formation sources (sources that have essentially simultaneous formation and release) and (2) reservoir sources (materials or places that contain previously formed CDDs/CDFs or dioxin-like PCBs that are rereleased to the environment). The contemporary formation sources are discussed in Chapters 3 through 10, and the reservoir sources are discussed in Chapter 11.

This document also classifies sources into five broad categories based mainly on their formation process:

- **Combustion.** CDDs/CDFs are formed in most types of combustion. This document addresses waste incineration, sources related to power/energy generation, a variety high temperature sources (including cement kilns, asphalt plants, carbon reactivation furnaces, and others) and minimally controlled or uncontrolled sources (including landfill gas flares/fires, forest fires, backyard trash burning in barrels, and others).
- **Metals Smelting/Refining.** This category includes sources that are involved in metals smelting, refining, and processing**.**
- **Chemical Manufacturing.** CDDs/CDFs can be formed as by-products in a variety of chemical manufacturing operations. These include chlorine-bleached wood pulp, chlorinated phenols (e.g., pentachlorophenol), PCBs, chlorobenzenes, phenoxy herbicides (e.g., 2,4-D and 2,4,5-T), and chlorinated aliphatic compounds (e.g., ethylene dichloride, vinyl chloride, polyvinyl chloride).
- **Biological, Photochemical, and Other Natural Processes.** CDDs/CDFs can form via biological processes such as the action of microorganisms on chlorinated phenolic compounds and also during photolysis of highly chlorinated phenols.
- **Reservoirs.** Reservoirs are environmental compartments and materials that have the capacity to store previously formed CDDs/CDFs or dioxin-like PCBs. These

compounds are thus sequestered from the open and circulating environment. Potential reservoirs include soils, sediments, and biota as well as some anthropogenic materials, such as PCP-treated utility poles. Dioxin-like compounds in these reservoirs have the potential for redistribution and circulation in the environment through the physical processes such as leaching, volatilization, erosion, sedimentation, and deposition. Whenever dioxins are released from their place of storage back into the circulating environment, the reservoir is considered a source of dioxin.

The approach used to estimate the emissions from most sources is based on an emission factor which relates mass of dioxins released into the environment with some measure of activity (e.g., kilograms of material processed per year, vehicle miles traveled per year, liters of wastewater discharged per year). The emission factor representing a class of facilities is developed by averaging the emission factors across the tested facilities in the class. This average emission factor is then multiplied by the measure of activity for the class to get total releases.

In this update, a revised approach has been developed to characterize the confidence ratings of the release estimates. The revised approach maintains the three major categories previously used, i.e., (1) the quantitative inventory [which now includes the sum of the previous confidence ratings that were subdivided into Class A, B, or C], (2) the preliminary release estimates [previously assigned a rating of Class D], and the unquantifiable sources [previously assigned a rating of Class E]. The major changes are the elimination of the Class A, B, or C confidence distinctions in the quantitative inventory and the addition of the quantitative uncertainty analysis of the quantitative inventory (presented in Section 1.3.6). The old Class A, B, and C confidence ratings were eliminated because they were too subjective and difficult to apply in a consistent fashion. Also, it was judged that confidence ratings for the individual source classes were less essential because a new quantitative uncertainty analysis has been added (see discussion below).

Key components of both the old and new schemes for classifying facilities are the criteria for deciding whether a source belongs in the quantitative inventory or the preliminary class. This update uses more specific guidance for making this decision. In order for a source to be included in the quantitative inventory, it must (a) have emission tests for at least two units/source types with sufficient documentation to directly derive emission factors, (b) the measured emission factors must be reasonably consistent or have understandable differences, (c) the emission factor tests must represent units that are reasonably typical of the class and (d) the activity estimates must be based on source-specific surveys.

The actual magnitude of releases from the preliminary sources could be significantly lower or higher than estimated. Although EPA does not support including them in the quantitative inventory at this time, some of these preliminary sources have the potential of being major contributors of releases to the environment. Accordingly, they are important to identify and could be used to help set priorities for future research and data collection. As the uncertainty around these sources is reduced, they will be included in future inventory calculations.

Results

Eighty source categories were identified with the potential for dioxin emissions. An overview of the total releases to air, land, water, and products is provided in Table ES-2. The major conclusions regarding CDD/CDF releases from contemporary formation sources are presented below:

- The total releases under the national quantitative inventory for 1987 in g WHO_{98} TEQ_{DF} were 15,000 to air, 2,400 to land, 360 to water, and 36 to products.
- The total releases under the national quantitative inventory for 1995 in g WHO_{98} TEQ_{DF} were 3,400 to air, 2,400 to land, 30 to water, and 47 to products.
- The total releases under the national quantitative inventory for 2000 in g WHO_{98} TEQ_{DF} were 2,300 to air, 2,300 to land, 28 to water, and 7 to products.

Table ES-2. Overview of total releases to air, land, water, and products in the updated inventory

Year	Releases (g WHO_{98} TEQ)			
	Air	**Land**	**Water**	**Products**
1987	15,000	2,400	360	36
1995	3,400	2,400	30	47
2000	2,300	2,300	28	7

- The top three quantified air sources in 2000 were:
  - forest fires (730 g WHO_{98} TEQ_{DF}),
  - backyard barrel burning of refuse (600 g WHO_{98} TEQ_{DF}), and
  - medical waste incinerators (400 g WHO_{98} TEQ_{DF}).

- Sources with preliminary release estimates have the potential for large releases of dioxin-like compounds. While not included in the current quantitative estimates listed above, future inclusion of these sources could change current release estimates. The largest preliminary sources in the current report are:
  - accidental fires at landfills (1,300 g WHO_{98} TEQ_{DF} to air in 2000), and
  - land clearing debris burning (85 g WHO_{98} TEQ_{DF} to air in 2000).
- A total of 20 contemporary formation sources were identified as having unquantifiable releases to one or more media. Information suggests these may be sources of dioxin-like compounds, but it is insufficient to make a national estimate of releases.
- The chemical product with the largest amount of CDD/CDF is pentachlorophenol, but the environmental releases associated with this product (primarily used to treat wood) could not be estimated. Release estimates could only be made for 2,4-D, where it can be assumed that the entire amount produced is released to the environment.

The environmental releases of dioxin-like PCBs have not been well characterized. PCBs were not produced during the reference years, but are still present in capacitors, transformers, building materials and other products in use today. No estimates could be made for releases from these in-use products. Only one source (backyard barrel burning) was judged to have adequate data to support quantitative air-release estimates for dioxin-like PCBs: 41, 43, and 34 g WHO_{98} TEQ_{P} for the years 1987, 1995, and 2000, respectively. Similarly, only two sources (backyard barrel burning and municipal wastewater treatment) were judged to have adequate data to support quantitative land release estimates for dioxin-like PCBs: 52, 78, and 20 g WHO_{98} TEQ_{P} for the years 1987, 1995, and 2000, respectively. Also, only preliminary estimates could be made for 6 sources, and 10 sources were identified as being unquantifiable. Although the information is limited, it suggests that, in terms of TEQs, PCB releases are much lower than CDD/CDF releases.

Soil is likely to be the reservoir source with the greatest potential for release of CDD/CDFs and PCBs to other environmental media, particularly to water. This is due to its relatively large mass of stored CDD/CDFs and PCBs and the existence of demonstrated transport mechanisms for intermedia exchange, e.g., soil erosion to surface waters and particle resuspension to air.

Discussion

Some observations about how releases have changed over the reference years can be made for the quantified sources. It is important to understand, though, that these observations do not include the sources classified as preliminary or unquantifiable. Some of the preliminary sources are potentially very large and, if confirmed and included in future quantitative estimates, could change the trend observations based on the currently quantified sources. With this caveat in mind, the following trends were identified. In terms of total releases from all media, a 67% reduction occurred from 1987 to 1995, a 23% reduction occurred from 1995 to 2000, and a 74% reduction occurred from 1987 to 2000.

Significant amounts of the dioxin-like compounds produced annually in the United States are not considered releases to the open and circulating environment and are not included in the national inventory. Examples include dioxin-like compounds generated internal to a process but destroyed before release and waste streams that are disposed of in approved landfills.

A number of contemporary formation sources were classified as preliminary or unquantifiable and, therefore, were not included in the inventory. The largest contemporary formation preliminary source is accidental fires at municipal solid waste landfills. This source has the potential to significantly increase the release estimates for 2000 if preliminary estimates are confirmed.

A series of analyses were used to assess the uncertainties of the quantitative inventory. This analysis was limited to the air and land releases from the top sources (accounting for over 90% of the releases) in 2000. This first involved using a propagation of error approach, which estimates the variance for the air emissions from each source and sums these to get the overall variance in total emissions. Multiple factors contribute to the uncertainty in the emission estimate for a class of facilities. These include sampling error which reflects the number of facilities tested out of the total, the representativeness of the tests of long term conditions, and measurement error from inaccuracies in the stack monitoring and chemical analysis. The propagation of error approach used here assumes that the variability in the emissions from the sampled facilities is an indication of the possible uncertainty in the emissions from the whole class of facilities. The analysis concludes that the total air releases from the top sources in 2000 sum to 2,100 g TEQ/year with a standard deviation of 1,300 g TEQ/year.

Secondly, a probabilistic analysis was conducted to evaluate the uncertainties in the air releases. All emission factors were assumed to have log normal distributions with means and standard deviations based on an arithmetic analysis of the data. A Monte Carlo analysis was conducted using the Crystal Ball program. A total of 10,000 simulations were run, producing a mean of 2,100 g TEQ and standard deviation of 1,100 g TEQ, which are very similar to the results of the propagation-of-error approach described above. Percentiles were estimated as 1,100 g TEQ for 10%, 1,800 g TEQ for 50%, and 3,300 g TEQ for 90%. These percentiles can be interpreted as the probability that the emissions will less than or equal to the specified amount.

Finally, further analysis is offered on the uncertainties associated with the forest fire air releases. These uncertainties are especially important to evaluate because they are the largest source and have high uncertainty in the emission factor. Both chamber studies and field studies have been used to measure these emissions. The field data suggest an emission factor of 0.95 ng TEQ/kg, and the chamber data suggest an emission factor of 7.5 ng TEQ/kg. If the lower emission factor is used, the forest fires would have a release of 230 g TEQ, and the total releases across the nine top sources in 2000 would be 1,600 g TEQ. Similarly, if the higher emission factor is used, the forest fires would have a release of 1,800 g TEQ, and the total releases across the nine top sources in 2000 would be 3,200 g TEQ.

The 2000 land releases were dominated by backyard barrel burning which had releases of 1,900 g WHO_{98} TEQ (88% of the total) and the uncertainty analysis for land releases was limited to this one source. The releases from backyard barrel burning were based on a study by Lemieux (1997). Ash samples from the experiments were combined, resulting in two composite samples, one for recyclers (2,700 ng WHO_{98} TEQ_{DF} /kg ash) and one for nonrecyclers (620 ng WHO_{98} TEQ_{DF} /kg ash). The final emission factor was based on the average of these values (1,700 ng WHO_{98} TEQ_{DF} /kg ash). The limited data do not allow statistical analyses such as that done for the air releases. Instead a potential range of releases was estimated based on the lower and upper emission factor estimates. The activity estimate for 2,000 was 1.2 MMT. Combining this value with the lower emission factor yields a release estimate of 740 g WHO_{98} TEQ. Combining the activity with the higher emission factor yields a release estimate of 2,800 g WHO_{98} TEQ. Accordingly the potential range of releases is 740 to 2,800 g WHO_{98} TEQ. Relative to the average value (1,900 g WHO_{98} TEQ), the lower estimate is 62% less and the upper estimate is 46% more.

Changes from 2006 Document

This discussion summarizes the changes from the 2006 report to the present report. Quantitative release estimates of CDD/CDFs to air increased for all years. The changes reflect the addition of new sources and adjustments to emission factors used for municipal and medical waste incinerators. The largest new source was forest fires which was previously classified as preliminary and not included in the quantitative inventory. Based on a number of new studies, it was decided that sufficient data were now available to move this source into the quantitative inventory. The forest fire releases in 2000 were about 4 times higher than 1987 and 1995 (due to more fires) causing a particularly large percent increase in that year. Other new sources added to the present document were secondary zinc smelters, glass manufacturers, lime kilns, agricultural burning, outdoor wood combustors, aluminum foundries, copper foundries and septic systems.

Quantitative release estimates of CDD/CDFs to land also increased for all years. These increases were due almost entirely to ash from backyard barrel burning which had not been addressed in the 2006 report. The quantitative releases to water and products did not change. The changes to the air and land releases are summarized in Table ES-3 below.

For dioxins, furans, and PCBs combined, the 2006 report indicated a 90% decrease in quantitative releases from 1987 to 2000. The updated report now indicates a 74% decrease over this time period. This reduction is due primarily to the addition of ash from backyard barrel burning (which remained relatively constant over the years) and air releases from forest fires (which had a particularly large release in 2000 as discussed above). The present document emphasizes that some of the preliminary sources are potentially very large and, if confirmed, could change the trend observations based on the currently quantified sources.

Table ES-3. Changes in quantitative release estimates from 2006 Report to present Report

	2006 Report	Present Report	Primary Reason for Change
Air Releases (g WHO_{98} TEQ)			
1987	13,500	15,000	Addition of forest fires, changes to municipal and medical waste incinerators
1995	3,200	3,400	Addition of forest fires, changes to municipal and medical waste incinerators
2000	1,300	2,300	Addition of forest fires, changes to municipal and medical waste incinerators
Land Releases (g WHO_{98} TEQ)			
1987	130	2,400	Addition of backyard barrel burners
1995	150	2,500	Addition of backyard barrel burners
2000	82	2,300	Addition of backyard barrel burners

1. BACKGROUND, APPROACH, AND CONCLUSIONS

1.1. BACKGROUND

This report presents an update to the dioxin source inventory published in 2006 (U.S. EPA, 2006). The update does not expand the scope of the document beyond the three reference years covered in the original document: 1987, 1995, and 2000.

This document is organized in a parallel fashion to the 2006 document, i.e., both documents use the same chapter/section sequence, although several additional sections have been added for new sources. This first chapter of the document is a complete rewrite and should be used as a replacement of Chapter 1 in the 2006 document. Chapter 2 on formation theory was not updated because it is not critical for the inventory. All subsequent chapters have sections organized by environmental media, i.e., releases to air, water, land, and products. Individual sections do not repeat the material in the 2006 document. Instead, they summarize new literature references and describe any changes in release estimates. At the end of each section, a table is presented (in a shaded text box to facilitate their identification and location) that provides all emission factors, activities, and release estimates. Most readers will only need to use this updated document because it describes all changes from the 2006 document and provides the bottom-line release estimates for all sources. Readers interested in further details about sources (i.e., process descriptions, summaries of the older literature, information on congener profiles, etc.) may find it helpful to consult the 2006 document.

1.1.1. Dioxin-Like Compounds

This document addresses specific compounds in the following chemical classes: chlorinated dibenzo-*p*-dioxins (CDDs), chlorinated dibenzofurans (CDFs), and polychlorinated biphenyls (PCBs). The physical/chemical properties of these compounds vary according to the degree and position of chlorine substitution. However, these compounds are generally hydrophobic, persistent in the environment, resistant towards metabolism, and bioaccumulate in the fatty tissues of animals and humans.

The CDDs include 75 individual compounds, CDFs include 135 individual compounds, and PCBs include 209 individual compounds. These individual compounds are technically referred to as congeners. 2,3,7,8-tetrachlorodibenzo-*p*-dioxin is the most widely studied (and historically considered to be the most toxic) chemical in this general class of compounds. A relatively small subset of the CDDs, CDFs, and PCBs are considered to have dioxin-like toxicity. These compounds have similar chemical structures and invoke a common battery of toxic responses as 2,3,7,8-TCDD. Only 7 of the 75 CDD congeners and 10 of the 135 CDF congeners are recognized to have dioxin-like toxicity; they are the ones with chlorine substitutions in, at a minimum, the 2, 3, 7, and 8 positions. There are 209 PCB congeners; of which, only 12 are recognized to have dioxin-like toxicity—those with four or more lateral chlorine atoms with one or no substitution in the *ortho* position. These compounds are sometimes referred to as coplanar, meaning that they can assume a flat configuration with rings aligned along the same plane. Other halogenated compounds have been identified as having dioxin-like toxicity, such as chlorinated naphthalenes, brominated dibenzo-*p*-dioxins and dibenzofurans, and similar compounds with a mix of bromines and chlorines. However, as discussed below, these are not addressed in this document.

The term "dioxins" has been used in several different ways in the literature. For example, it has been used to refer to TCDD only, all CDDs and CDFs, or subsets of these compounds. The present document uses "dioxins" to refer generally to the CDDs, CDFs, and PCBs that have dioxin-like toxicity. (This can also be defined as the 17 CDDs/CDFs and 12 coplanar PCBs with toxicity equivalence factors [TEFs] greater than zero; this concept of toxicity equivalence is discussed further in Section 1.1.2 below.) Similarly, the phrase "dioxin-like compounds" is used in this document to refer to only those compounds with established TEF values. As noted above, a number of other compounds have been suggested to have "dioxin-like toxicity," but these are not addressed in this document.

This document focuses primarily on the 17 CDDs/CDFs, with a more limited discussion of the 12 coplanar PCBs. This is because there are relatively little congener-specific data on PCB releases.

Table 1-1 provides a complete listing of the chemical nomenclature used in this report.

1.1.2. Toxicity Equivalence Factors

CDDs, CDFs, and PCBs are commonly found as complex mixtures when detected in environmental media, biological tissues, or releases from specific sources. Humans are likely to be exposed to mixtures of these compounds that vary by source and pathway, complicating the assessment of human health risk assessment. To address this problem, the concept of a "toxicity equivalence" (TEQ) has been developed.

TEFs compare the toxicity of each dioxin-like compound in the mixture to the well-studied 2,3,7,8-TCDD, historically considered the most toxic member of the group. The comparison procedure involves assigning individual TEFs to the 2,3,7,8-substituted CDD/CDF congeners and dioxin-like PCBs. To accomplish this, scientists have reviewed the toxicological databases and, with considerations of chemical structure, persistence, and resistance to metabolism, have agreed to ascribe specific "order-of-magnitude" TEFs for each dioxin-like congener relative to 2,3,7,8-TCDD, which is assigned a TEF of 1. The other congeners have TEF values ranging from 1 to 0.00001.

To apply this concept, the TEF of each congener present in a mixture is multiplied by the respective mass concentration, and the products are added to represent the 2,3,7,8-TCDD TEQ of the mixture (eq 1-1).

$$TEQ = \sum_{i=1}^{n} Concentration_i \times TEF_i \qquad (1\text{-}1)$$

A variety of TEF schemes have been developed since the 1980s. This can lead to confusion when a TEQ value is presented without a clear designation of which TEF scheme was used to calculate it. This document uses a nomenclature that distinguishes between the different TEF schemes and identifies the congener groups included in specific TEQ calculations:

- I-TEQ refers to toxic equivalents derived using the international TEF scheme adopted by EPA in 1989 (U.S. EPA, 1989).
- WHO_{94} TEQ refers to toxic equivalents derived using the 1994 World Health Organization (WHO) extension of the I-TEF scheme, which includes 13 dioxin-like PCBs (Ahlborg et al., 1994).
- WHO_{98} TEQ refers to toxic equivalents derived using the 1998 WHO update to the previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg et al., 1998).
- WHO_{2005} TEQ refers to toxic equivalents derived using the 2005 WHO update to the previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg et al., 2006).

Table 1-2 shows all four of these TEF schemes.

The nomenclature also uses subscripts to indicate which family of compounds is included in any specific TEQ calculation. Under this convention, a subscript D is used to designate dioxins, a subscript F is used to designate furans, and a subscript P is used to designate PCBs. As an example, WHO_{98} TEQ_{DF} would be used to describe a mixture for which only dioxin and furan congeners were determined and where the TEQ was calculated using the WHO_{98} scheme. If PCBs had also been determined, the nomenclature would be WHO_{98} TEQ_{DFP}. Note that in this document I-TEQ sometimes appears without the D or F subscripts. This indicates that the TEQ calculation includes both dioxins and furans.

This document uses the WHO_{98} TEF scheme as the primary basis for presenting TEQ estimates. While the WHO_{2005} TEFs are more current, the previous version of this document used the WHO_{98} TEFs. This document continues the use of the WHO_{98} TEFs to be consistent with the 2006 document, allowing for easy comparison. A limited number of estimates were generated using the newer TEF values, and it was seen that differences were inconsequential (data not provided).

Throughout this document, environmental release estimates are presented in terms of TEQs. This is consistent with previous versions of the inventory and is the common approach to dioxin sources inventories worldwide (UNEP, 2005). Doing so facilitates comparisons across sources. For the purposes of environmental fate modeling, however, it is important to use the individual CDD/CDF and PCB congener values rather than TEQs. This is because the physical/chemical properties of individual CDD/CDF congeners vary and, consequently, the congeners will behave differently in the environment. For example, the relative mix of congeners released from a stack cannot be assumed to remain constant during transport through the atmosphere and deposition to various media. Further, the bioavailability of dioxin congeners are different, so that bioaccumulation in the food chain up through humans results in different relative proportions of dioxins compared to the profile of dioxins to which animals and humans are exposed. Generally, human exposure to releases of dioxins from sources is a complex phenomena encompassing proximity to source, congener-specific fate and transport characteristics, and congener-specific bioavailability. For this reason, the amount of dioxins being emitted from a specific source may not translate directly into human exposure.

TEQ values are frequently based on some congeners that were not found above detection limits (DLs). Undetected values are commonly referred to using the term “nondetect,” or ND, and that terminology is adopted here. EPA risk assessments typically address this issue by assuming that NDs = 2DL. This document is not a risk assessment and uses a different approach. Here, it is assumed that NDs = 0. This assumption allows a consistent approach to this issue throughout the document. Because many studies did not provide DLs, the only practical, consistent approach is to assume NDs = 0. Many assessments also present TEQ estimates in two ways: first assuming NDs = 0 and then assuming NDs = 2 DL. Such comparisons are useful for illustrating the impact of DLs on TEQ calculations. This approach was used in some places in this document, but generally, it was not used for two reasons. First, it was not possible in many instances due to lack of DL information. Second, many release estimates are presented in terms of two TEF schemes and three reference years. Presenting all values with two ways of treating DLs, would increase complexity enough to compromise the readability of the document.

1.1.3. Regulatory Summary

Over the time frame represented by these inventories (1987–2000), EPA, states, and industry have worked to develop regulations limiting dioxin emissions. Although not all of these regulations are fully implemented yet, they have contributed to reductions in emissions from certain source categories (see time trend discussion in Section 1.3.3). Tables 1-3 through 1-8 present a synopsis of the principal EPA emission standards for the control of dioxin releases.

1.1.4. Information Sources

The references used to support this report are based on an intensive literature review of documents published in 2003 (or earlier) and selected documents published in 2004–2010. The report also used information from databases maintained by EPA’s Office of Air Quality Planning and Standards and Office of Resource Conservation and Recovery (ORCR).

An important reference in this field is the *Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases* issued by the United Nations Environment Programme in 2005 (UNEP, 2005). This document was produced to help support implementation of the Stockholm Convention on Persistent Organic Pollutants. This *Toolkit* provides a methodology to help countries just developing their inventories to estimate releases of CDD/CDF and to lead them through the process of enhancing and refining these inventories. It is intended to provide a consistent basis for assessing CDD/CDF releases over time and between countries. This updated inventory frequently references the *Toolkit* and discusses the recommended emission factors.

The EPA Toxics Release Inventory (TRI) began collecting data on PCBs in 1988 and on CDDs/CDFs in 2000 (U.S. EPA, 2003b). The TRI reporting of dioxin sources provides important information in the overall understanding of dioxin releases. These data were considered in this report for the purposes of identifying possible sources and as supportive evidence for where releases can occur, but they were not used for making quantitative release estimates because of the following considerations:

- With respect to PCBs, for reporting years 1988–2000, the TRI data are reported as total PCBs rather than on a congener-specific basis. Thus, it is unknown what portion of these releases are dioxin-like PCBs, and TEQs cannot be calculated.
- With respect to CDDs/CDFs, for reporting year 2000, the TRI data are reported as the sum of the 17 congeners with 2,3,7,8-chlorine-substituted compounds. Facilities had the option to report an estimate of the congener distribution for total releases, though many chose not to provide this information. Accordingly, much of the 2000 data could not be used to make TEQ estimates.
- The TRI data are self-reported, and facilities are not required to take measurements to support their emission estimates. Rather, they can be derived from emission factors or other methods. Facilities are also not required to describe the approach used to make the emission estimates. Consequently, it would be difficult to evaluate inconsistencies between these estimates and those in this inventory.
- The TRI reports include SIC codes but lack further details describing the facilities in terms of process, production, and pollution controls. Therefore, in many cases, it is not clear where a reporting facility fits into the classification system used in this report.

1.2. APPROACH

This section describes the key components of the approach used to develop the dioxin inventory. The discussion covers the selection of reference years, release types, how sources are classified, quantitative methods used to develop release estimates, and confidence ratings.

1.2.1. Reference Years

A central part of EPA's dioxin inventory is the organization of estimates of annual releases of dioxin-like compounds into reference years 1987, 1995, and 2000. The selection and use of three reference years provides a basis for comparing environmental releases over time.

The year 1987 was selected as the initial reference year because it was the earliest time when it was feasible to assemble a reasonably comprehensive inventory. Prior to that time, very little data existed on dioxin emissions from stacks or other release points. The first study providing the type of data needed for a national inventory was the EPA National Dioxin Study (U.S. EPA, 1987). The year 1987 also corresponds roughly with the time when significant advances occurred in emissions measurement techniques and in the development of high-resolution mass spectrometry and gas chromatography, which allowed analytical laboratories to detect low levels of CDD and CDF congeners in environmental samples. Soon after this time, a number of facilities began upgrades specifically intended to reduce CDD/CDF emissions. Consequently, 1987 emissions are representative of levels that occurred before the widespread installation of pollution control systems and pollution prevention techniques specifically designed to reduce dioxin releases from man-made sources into the air, land, and water.

EPA selected 1995 as the second reference year because it reflects the completion time of the first set of regulatory activities specifically tailored to reduce dioxin releases from major sources. By 1995, EPA had proposed or promulgated regulations limiting CDD/CDF emissions from municipal waste combustors (MWCs), medical waste incinerators, and pulp and paper mill facilities using bleached chlorine processes.

The year 2000 was chosen as the most current date that could be addressed when this effort began in 2002. Also, it corresponds to a reasonable time interval since 1995 when one could expect to see further changes occurring in releases as a result of continuing regulatory activities, voluntary actions on the part of industry, and facility closures.

1.2.2. Release Types

A comprehensive assessment of potential dioxin releases from a source requires consideration of all possible outputs. As diagrammed in Figure 1-1, the outputs of a process can be in the form of products, air emissions, water discharges, and solid residues. Solid residues can be used in products, land disposed or incinerated. Each source addressed in this document is evaluated in terms of all of these outputs. However, not all of the outputs are considered to be environmental releases. Outputs judged to have a reasonable likelihood for release to the circulating environment include all air emissions, water discharges, landfarmed wastes and products which are directly released to the open environment such as some pesticides. Outputs that are generally not considered an environmental release include waste disposal at lined landfills, intermediate products or internal waste streams or products containing tightly bound dioxins such as treated wood. Dioxins contained in some products or disposed in secure landfills may be released to the circulating environment at some time in the future. They are less likely to be released to the circulating environment during the same year that they enter into commerce or are landfilled. Consequently, these contained dioxins would not initially be considered environmental releases. Ideally, releases derived from such products and landfill practices of past years would be included in the inventory for the reference year in which the releases occur. Unfortunately, the current state of science does not support estimating when and to what degree such releases may occur. However, for informational purposes, and when sufficient information is available, this document provides estimates of the amount of dioxins contained in products or disposed in landfills.

1.2.3. Source Classes

Sources can be categorized in terms of when releases occur: (1) contemporary formation sources (sources that have essentially simultaneous formation and release) and (2) reservoir sources (materials or places that contain previously formed CDDs/CDFs or dioxin-like PCBs that are rereleased to the environment). The contemporary formation sources are discussed in Chapters 3 through 10, and the reservoir sources are discussed in Chapter 11.

This document also classifies sources into five broad categories based mainly on their formation process:

1. **Combustion.** CDDs/CDFs are formed in most types of combustion. These sources are addressed in Chapters 3–6:
    - Chapter 3 covers sources involved in waste incineration including municipal solid waste (MSW), hazardous waste, medical waste, sewage sludge, and other types of waste.

- Chapter 4 covers sources related to power/energy generation including motor vehicles and combustion of wood, oil, and coal.
- Chapter 5 covers a variety high temperature sources including cement kilns, asphalt plants, carbon reactivation furnaces, and others.
- Chapter 6 covers minimally controlled or uncontrolled sources and includes landfill gas flares/fires, forest fires, backyard trash burning in barrels, and others.

2. **Metals Smelting/Refining.** This category includes sources that are involved in metals smelting, refining, and processing**.** They are addressed in Chapter 7.
3. **Chemical Manufacturing.** CDDs/CDFs can be formed as by-products in a variety of chemical manufacturing operations. These are addressed in Chapter 8 and include chlorine-bleached wood pulp, chlorinated phenols (e.g., pentachlorophenol), PCBs, chlorobenzenes, phenoxy herbicides (e.g., 2,4-D and 2,4,5-T), and chlorinated aliphatic compounds (e.g., ethylene dichloride, vinyl chloride, polyvinyl chloride).
4. **Biological, Photochemical, and Other Natural Processes.** CDDs/CDFs can form via biological processes such as the action of microorganisms on chlorinated phenolic compounds and also during photolysis of highly chlorinated phenols. These are addressed in Chapter 9.
5. **Reservoirs.** Reservoirs are environmental compartments and materials that have the capacity to store previously formed CDDs/CDFs or dioxin-like PCBs. These compounds are thus sequestered from the open and circulating environment. Potential reservoirs include soils, sediments, and biota as well as some anthropogenic materials, such as PCP-treated utility poles. Dioxin-like compounds in these reservoirs have the potential for redistribution and circulation in the environment through the physical processes such as leaching, volatilization, erosion, sedimentation, and deposition. Whenever dioxins are released from their place of storage back into the circulating environment, the reservoir is considered a source of dioxin. Reservoirs are addressed in Chapter 11.

Note that Chapters 3–9, discussed above, address releases of only CDDs and CDFs. Contemporary formation sources that releases dioxin-like PCBs are discussed in Chapter 10. Reservoir sources that release CDDs, CDFs, or PCBs are covered in Chapter 11.

1.2.4. Quantitative Method for Inventory of Sources

Estimates of CDD/CDF releases to the air from individual facilities are derived from stack testing, which provides the concentration of CDD/CDF in the flue gas. This is combined with the flue gas flow rate and operating time to estimate annual releases as shown in equation 1-2:

$$E_{TEQ} = \frac{C\ F_v\ CF\ H}{10^9\ ng/g} \quad (1\text{-}2)$$

where

E_{TEQ} = annual TEQ emissions (g/year)

C = combustion flue gas TEQ concentration (ng/dscm) (20°C, 1 atm; adjusted to 7% O_2)

F_v = volumetric flow rate of combustion flue gas (dscm/hour) (20°C, 1 atm; adjusted to 7% O_2)

CF = capacity factor; fraction of time that the facility operates

H = total hours in a year (8,760 hour/year)

A similar approach is used for estimating facility releases to other media. For example, releases to water would involve multiplying the concentration of the CDD/CDF in the effluent by the discharge rate. Ideally, national release estimates would be derived by testing every facility in a source category, estimating their releases, and summing across facilities. This was feasible in only a few situations such as wastewater releases from chlorine-bleached pulp and paper mills. For all other source categories, EPA used a method to extrapolate from tested to untested sources and derive national estimates of environmental releases. As explained below, this method is based on the use of emission factors and activity levels.

The first step in this approach is to use emission monitoring data to derive an emission factor (or series of emission factors) deemed to be representative of the source category (or segments of a source category that differ in terms of configuration, fuel type, air pollution control equipment, etc.). The emission factor relates mass of dioxins released into the environment with some measure of activity (e.g., kilograms of material processed per year, vehicle miles traveled per year, liters of wastewater discharged per year). For individual facilities, it is calculated using the following equation (eq 1-3):

$$EF = \frac{E_{TEQ}}{A} \quad (1\text{-}3)$$

where

EF = emission factor (ng TEQ/kg)

E_{TEQ} = annual TEQ emissions (g/year) (see eq 1-1)

A = annual activity rate (kg/year)

A similar approach is used for estimating emission factors for releases to other media. For example, an emission factor for releases to water would involve dividing the annual TEQ release rate via effluent discharges by the annual waste processing rate (or some other measure of activity). The emission factor representing a class of facilities is developed by averaging the emission factors across the tested facilities in the class. This average emission factor is then multiplied by the measure of activity for the nontested facilities in the class (e.g., total kilograms of material processed by these facilities annually). Finally, releases are summed for the tested facilities and nontested facilities. In general, this procedure can be represented by the following equations (eq 1-4 and 1-5):

$$R_{Total} = \sum_{i=1}^{n} R_{Tested,i} + \sum_{i=1}^{n} R_{Untested,i} \qquad (1\text{-}4)$$

$$R_{Total} = \sum_{i=1}^{n} R_{Tested,i} + \sum_{i=1}^{n} EF_{Untested,i} \times A_i \qquad (1\text{-}5)$$

where

R_{Total} = annual releases from all facilities (g TEQ/year)

$R_{Tested,\ i}$ = annual releases from all tested facilities in class i (g TEQ/year)

$R_{Untested,\ i}$ = annual releases from all untested facilities in class i (g TEQ/year)

$EF_{Untestedi}$ = mean emission factor for untested facilities in class i (g TEQ/kg)

A_i = activity measure for untested facilities in class i (kg/year)

Note that even though this approach is presented using the term “emission factor,” it is intended to apply to releases to all media. The method was originally developed for evaluating air emissions and is thus traditionally defined using this term. Also note that for most sources, a small percentage of the facilities had been tested. In these cases, it was not worth the effort to estimate releases from tested and untested facilities separately as shown in equation 1-5. Instead, the average emission factor was applied to the activity level for the whole class.

Some source categories are made up of facilities that vary widely in terms of design and operating conditions. For these sources, as explained above, an attempt was made to create subcategories that grouped facilities with common features and then to develop separate emission factors for each subcategory. Implicit in this procedure is the assumption that facilities with similar design and operating conditions should have similar CDD/CDF-release potential. For most source categories, however, the specific combination of features that contributes most to CDD/CDF or dioxin-like PCB releases is not well understood. Therefore, the procedure for how to best subcategorize a source category was often problematic. For each subcategorized source category in this document, a discussion is presented about the variability in design and operating conditions, what was known about how these features contributed to CDD/CDF or dioxin-like PCB releases, and the rationale for creating subcategories.

The emission factors developed for the inventory are intended to be used for estimating total emissions for a source category rather than emissions from individual facilities. If applied to individual facilities, the emission factor would likely overestimate releases from some facilities and underestimate others. When it is applied to a class of facilities, these over- and underestimates balance out to some extent. Thus, in using these emission factors, one can place significantly greater confidence in an emission estimate for a class than in an estimate for any individual facility. Given the limited amount of data available for deriving emission factors and the limitations of our understanding about facility-specific conditions that determine formation and control of dioxin-like compounds, the current state of knowledge cannot support the development of emission factors that can be used to accurately estimate emissions on an individual facility-specific basis.

1.2.5. Uncertainties

The quantitative inventory has multiple uncertainties, including the following:

- It is based on emissions testing that covers a small fraction of the facilities in most classes.
- Facility testing is generally over short time periods during normal operating conditions. The releases during start-up and shutdown may be different than normal operations. For

conventional pollutants, releases are generally greater during these times, but dioxin releases may occur at rates lower or higher than normal operations due to changes in formation conditions. Recent efforts by EPA's Office of Air Quality Planning and Standards are addressing emissions that occur during start-up and shutdown and may allow these uncertainties to be addressed in the future.

- Testing has sometimes found individual facilities within a class with unusually low or high dioxin releases for unknown reasons.
- It does not include the emissions from a number of suspected sources that lack sufficient data to make reliable estimates (defined below as preliminary or unquantifiable sources). Because many types of sources release dioxins, it is likely that some have been missed completely.

All of these factors introduce uncertainty into the release estimates. While most of these uncertainties are impossible to characterize, some can be evaluated as discussed below.

The original inventory report (U.S. EPA, 2006) used a qualitative scheme to assess uncertainty. This scheme assigned qualitative confidence ratings to the emission factors, activity levels, and release estimates. The five confidence ratings (Class A, B, C, D, or E) were defined as follows:

- Classes A, B, and C—Class A indicates high confidence, Class B indicates medium confidence, and Class C indicates low confidence. These three classes make up the quantitative inventory.
- Class D—For many source categories, very limited release data were available and judged to be inadequate to support development of reliable quantitative release estimates for one or more media. For some of these source categories, sufficient information was available, however, to make preliminary estimates of releases. These preliminary estimates were assigned to Class D.
- Class E—For other sources, no dioxin release data were available, but either formation theory or similarity to other sources with measured releases suggested that releases may occur. These sources were identified to the extent possible, but no release estimates could be made. They were assigned to Class E.

The overall confidence rating assigned to an emissions estimate was determined by the lowest rating assigned to either the emission factor or activity level.

In this update, a revised approach has been developed to characterize the confidence ratings of the release estimates. The revised approach maintains the three major categories previously used, i.e., (1) the quantitative inventory [which now includes the sum of the previous confidence ratings that were subdivided into Class A, B, or C], (2) the preliminary release estimates [previously assigned a rating of Class D], and the unquantifiable sources [previously assigned a rating of Class E]. The major changes are the elimination of the Class A, B, or C confidence distinctions in the quantitative inventory and the addition of the quantitative uncertainty analysis of the quantitative inventory (presented in Section 1.3.6). The old Class A, B, and C confidence ratings were eliminated because they were too subjective and difficult to apply in a consistent fashion. Also, it was judged that confidence ratings for the individual source classes were less essential because a new quantitative uncertainty analysis has been added. It was determined that the more important issue was the uncertainty in the total national release estimate. Accordingly, the new quantitative approach focuses on this issue.

Key components of both the old and new scheme for assessing uncertainty are the criteria for deciding whether a source belongs in the quantitative inventory or preliminary class. This update uses more specific guidance for making this decision. In order for a source to be included in the quantitative inventory, it must (a) have emission tests for at least two units/source types with sufficient documentation to directly derive emission factors, (b) the measured emission factors must be reasonably consistent or have understandable differences, (c) the emission factor tests must represent units that are reasonably typical of the class and (d) the activity estimates must be based on source-specific surveys.

The actual magnitude of releases from the preliminary sources could be significantly lower or higher than estimated. Although EPA has chosen not to include them in the quantitative inventory, it must be emphasized that some of the preliminary sources have the potential of being major contributors of releases to the environment. Accordingly, they are important to identify and can be used to help set priorities for future research and data collection. As the uncertainty around these sources is reduced, they will be included in future inventory calculations.

The data used in this document come from hundreds of studies which reported values using a wide range of significant figures. In the present report, the decision about how many significant figures to use began with the general policy to report previously published data in the same manner as in the original publication and to report calculated values with a number of significant figures no more than the input with the least number of significant figures. This document reports all emission factors and releases in TEQs. TEQs are derived from toxicity equivalency factors that are presented with only one significant figure. Although this suggests that all TEQ estimates should be presented with only one significant figure, they are commonly reported to 2 or more significant figures in the literature. Limiting the number of significant figures to 1 for the larger release estimates introduces large rounding adjustments. Therefore, it was decided to present the release estimates to 2 significant figures when they equal or exceed 10 g TEQ/year. Releases less than 10 g TEQ/year were limited to only 1 significant figure. Releases less than 0.1 g TEQ/year were presented as <0.1 to reflect the additional uncertainty in such small estimates and because they have negligible contributions to the total releases. Similarly the emission factors were reported to 2 significant figures for values that equal or exceed 0.1 ng TEQ/kg and to 1 significant figure for values less than 0.1 ng TEQ/kg. Activity estimates are typically very large numbers and are generally known with more certainty than the emission factors. Therefore, it was decided to report activities to 3 or fewer significant figures.

1.3. SUMMARY AND CONCLUSIONS

Table 1-12 lists all of the quantitative and preliminary CDD/CDF release estimates developed in this document. It also identifies all of the unquantifiable sources. Where feasible, the table presents release estimates to air, water, land, and products for each reference year. As discussed earlier, the preliminary release estimates are not part of the official inventory, but they are included in this table to provide a complete picture of what is known and unknown about potential CDD/CDF releases.

Table 1-13 lists all of the quantitative and preliminary PCB release estimates and unquantifiable PCB sources. It is organized in the same manner as Table 1-12. Both Tables 1-12 and 1-13 include only contemporary formation sources, i.e., those which form CDD/CDFs during the same time frame as when the releases occur. Releases can also occur from reservoirs, which are defined as materials or places that contain previously released CDD/CDFs or dioxin-like PCBs and have the potential for redistributing these compounds into the environment. Tables 1-14 (CDD/CDFs) and 1-15 (PCBs) present releases for reservoirs. Releases from reservoirs are not considered to be part of the official inventory because they are not original releases but rather the recirculation of past releases.

1.3.1. Contemporary Formation Sources

Eighty source categories were identified with the potential for dioxin emissions. The major conclusions regarding CDD/CDF releases from contemporary formation sources are presented below:

- The total releases under the national quantitative inventory for 1987 in g WHO_{98} TEQ_{DF} were 15,000 to air, 2,400 to land, 360 to water, and 36 to products.
- The total releases under the national quantitative inventory for 1995 in g WHO_{98} TEQ_{DF} were 3,400 to air, 2,400 to land, 30 to water, and 47 to products.
- The total releases under the national quantitative inventory for 2000 in g WHO_{98} TEQ_{DF} were 2,300 to air, 2,300 to land, 28 to water, and 7 to products.
- Table 1-16 presents a ranking of the top five sources based on the magnitude of environmental release by year and media. The top three air sources in 2000 were forest fires (730 g WHO_{98} TEQ_{DF}), backyard barrel burning of refuse (600 g WHO_{98} TEQ_{DF}), and medical waste incinerators (400 g WHO_{98} TEQ_{DF}).
- Preliminary sources have the potential for large releases of dioxin-like compounds. The largest preliminary sources are accidental fires at landfills (1,300 g WHO_{98} TEQ_{DF} to air in 2000) and land clearing debris burning (85 g TEQ_{DF} to air in 2000).
- A total of 20 contemporary formation sources were identified as having unquantifiable releases to one or more media. Information suggests these may be sources of dioxin-like compounds, but it is insufficient to make a national estimate of releases.
- Table 1-17 lists the amounts of CDD/CDF found in several chemical products. The largest amounts are found in pentachlorophenol, but the environmental releases associated with this product (primarily used to treat wood) could not be estimated. Release estimates could only be made for 2,4-D, where it can be assumed that the entire amount produced is released to the environment.

The environmental releases of dioxin-like PCBs have not been well characterized. PCBs were not produced during the reference years, but are still present in capacitors, transformers, building materials and other products in use today. No estimates could be made for releases from these in-use products. As shown in Table 1-13, only one source (backyard barrel burning) was judged to have adequate data to support quantitative air-release estimates of 41, 43, and 34 g WHO_{98} TEQ_{P} for the years 1987, 1995, and 2000, respectively. Similarly, only two sources (backyard barrel burning and municipal wastewater treatment) were judged to have adequate data to support quantitative land release estimates of 52, 78, and 20 g WHO_{98} TEQ_{P} for the years 1987, 1995, and 2000, respectively. Also, preliminary estimates could be made for 6 sources, and 10 sources were identified as being unquantifiable. Although the information is limited, it suggests that, in terms of TEQs, PCB releases are much lower than CDD/CDF releases.

1.3.2. Reservoir Sources

Soil is likely to be the reservoir source with the greatest potential for release of CDD/CDFs and PCBs to other environmental media, particularly to water. This is due to its relatively large mass of stored CDD/CDFs and PCBs and the existence of demonstrated transport mechanisms for intermedia exchange, e.g., soil erosion to surface waters and particle resuspension to air.

The preliminary estimates of CDD/CDF TEQs in soil runoff to waterways (Table 1-14) are more than 100 times greater than known industrial point-source releases to water. It is unclear how much of the soil erosion and runoff represents recently deposited CDD/CDFs from primary sources or longer-term accumulation. Much of the eroded soil comes from tilled agricultural lands, which would include a mix of CDD/CDFs from various deposition times.

Five possible product reservoirs were identified: bleached chemical wood pulp, pentachlorophenol, vinyl chloride, chloranil, and PCBs. No estimates could be made for the total mass of CDD/CDFs contained in these reservoirs or their releases.

1.3.3. Time Trends

Some observations about how releases have changed over the reference years can be made for the quantified sources. It is important to understand, though, that these observations do not include the sources classified as preliminary or unquantifiable. Some of the preliminary sources are potentially very large and, if confirmed, could change the trend observations based on the currently quantified sources. With this caveat in mind, the following trends were identified.

Table 1-18 shows the total releases in 1987, 1995, and 2000 and the percent changes from 1987 to 1995, 1995 to 2000, and 1987 to 2000. A few sources were included in some reference years and not others due to lack of information. Removal of these sources from the yearly totals only had a large effect on the water release estimates. Thus, the water totals presented in Table 1-18 reflect this adjustment (discussed further below).

In terms of total releases from all media, a 67% reduction occurred from 1987 to 1995, a 23% reduction occurred from 1995 to 2000, and a 74% reduction occurred from 1987 to 2000. Further insight can be gained from examining trends occurring in each medium:

- Air—The reductions in total air releases were 85% from 1987 to 2000. Three sources accounted for over 100% of the reduction: municipal waste incinerators (74%), medical waste incinerators (18%), and secondary copper smelters (8%). These reductions were offset by increases in releases from forest fires, which increased by a factor of 4 from 1987 to 2000: 180 g WHO_{98} TEQ in 1987 to 730 g WHO_{98} TEQ in 2000. Table 1-16 shows that the nonindustrial sources have moved to the top of the rankings.
- Land—Very little change occurred in land releases over the reference years (4% reduction in 1987 to 2000). Land release estimates could only be made for seven sources, and these were dominated by structural fires and backyard barrel burning.
- Water—Only one source—bleached pulp and paper mills—had water release estimates for each of the reference years. Thus, the trend analysis is limited to this source. The reductions from 1987 to 2000 were almost 100% (360 to 1 g WHO_{98} TEQ).
- Product—The reductions in product releases were 81% from 1987 to 2000. Release estimates could only be made for two products: 2,4-D and land-applied municipal wastewater treatment sludge. Assuming that dioxins have been eliminated from 2,4-D by 2000 (data are lacking to confirm this), this reduction is virtually 100%. Releases from sludge actually increased from 1987 to 2000, although the amounts were low (i.e., 7 $gWHO_{98}$ TEQ in 2000).

One way to assess the validity of these trends is to consider the uncertainties associated with the release estimates. As discussed in Section 1.3.6 a propagation of error analysis was used to derive the standard deviation for the air release estimate for the year 2000 based on the top 9 sources (releases = 2,100 g WHO_{98} TEQ with SD = 1,300). A similar analysis of the 1987 data suggests that the air releases (14,000 g WHO_{98} TEQ) have an SD of 3,000. This means that the 1987 releases minus two SDs still exceeds the 2000 releases plus two SDs. As a point of comparison, for normal distributions, 95% of the probability falls within two SDs of the mean. Although the distribution of possible releases is likely skewed, the large difference between the total releases and their associated SDs suggest that little overlap occurs between the possible range of estimates for the 1987 and 2000 releases. Thus the results of this analysis strongly support the observation of a downward trend.

Finally further evidence of future downward trends in dioxin emissions to the air can be based on recent rulemaking and data collection efforts conducted by EPA's Office of Air Quality Planning and Standards. The Clean Air Act requires that regulation support efforts include estimates of current nationwide baseline emissions and future reductions that will occur after full implementation of the regulations. The list below shows these estimates for regulation support activities that have occurred after 2000:

- Sewage sludge incineration – Baseline estimates for 2010 were 0.4 g WHO_{2005} TEQ/yr with future reductions of 0 g WHO_{2005} TEQ/yr (ERG, 2011a). This compares to the estimates presented here of 10 g WHO_{98} TEQ/yr for the year 2000.
- Medical waste incineration – Baseline estimates for 2008 were 0.83 g WHO_{2005} TEQ/yr with future reductions of 0.66 g WHO_{2005} TEQ/yr (Holloway, 2009). This compares to the estimates presented here of 400 g WHO_{98} TEQ/yr for the year 2000.
- Secondary copper smelting - US EPA concluded that no dioxin emissions occurred from secondary copper smelting plants in 2006 because all had been shut down (Federal Register, 2006). This compares to the estimates presented here of 0.9 g WHO_{98} TEQ/yr for the year 2000.
- Industrial, Commercial, Institutional Boilers and Process Heaters - Baseline estimates for 2008 were 37 g WHO_{2005} TEQ/yr with future reductions of 23 g WHO_{2005} TEQ/yr (Singleton and Gibson, 2011). This source category does not match exactly with the source definitions used here. It includes industrial oil burning boilers (7 g WHO_{98} TEQ/yr for the year 2000) and industrial coal burning boilers (41 g WHO_{98} TEQ/yr for the year 2000)
- Commercial/Industrial solid waste incineration - Baseline estimates for 2010 were 165 g total CDD/Fs with future reductions of 115 g total CDD/Fs (ERG, 2011b). Unfortunately as of press time for the present document, no TEQ conversions were available for these estimates, making comparisons difficult. Also this source category does not match exactly with the source definitions used here.

1.3.4. Sources Not Included in the Inventory

Significant amounts of the dioxin-like compounds produced annually in the United States are not considered releases to the open and circulating environment and are not included in the national inventory. Examples include dioxin-like compounds generated internal to a process but destroyed before release and waste streams that are disposed of in approved landfills.

A number of contemporary formation sources were classified as preliminary or unquantifiable and, therefore, were not included in the inventory. The largest contemporary formation preliminary source is accidental fires at MSW landfills. This source has the potential to significantly increase the release estimates for 2000 if preliminary estimates are confirmed.

The possibility remains that truly undiscovered sources exist. Many of the sources that are well accepted today were discovered only in the recent past. For example, CDDs/CDFs in stack emissions from MWCs were not detected until the late 1970s; CDDs/CDFs in the wastewater effluent from bleached pulp and paper mills were found unexpectedly in the mid-1980s; iron ore was not recognized as a source until the early 1990s.

1.3.5. Congener Profiles of CDD/CDF Sources

The 2006 document presented congener profiles for a number of sources, showing the relative amounts of CDD/CDF congeners in environmental releases. While these profiles can be useful for identifying sources, they are not essential to the inventory itself. Therefore, they were not updated in the present document.

1.3.6. Uncertainty Analysis

The purpose of this section is to present a quantitative analysis of the uncertainty in the total release estimates. Given the wide scope of this document (over 80 source categories, three reference years and four release media), a number of steps were taken to simplify this analysis. First, it was limited to the 2000 releases because these are the most current. Second, it was limited to the air and land releases. The releases to the other media are so much smaller, they will have negligible impact on the overall uncertainty (air—2,300 g WHO_{98} TEQ, land—2,200 g WHO_{98} TEQ, water—28 g WHO_{98} TEQ and product—7 g WHO_{98}-TEQ). Finally, the number of source categories included in the analyses was limited to the largest ones, with cumulative contributions of about 90% of the total releases.

1.3.6.1. *Air Releases*

The uncertainty was first evaluated using a propagation of error approach. This involves estimating the variance for the emissions from each source and summing these to get the overall variance in total emissions. Multiple factors contribute to the uncertainty in the emission estimate for a class of facilities. These include sampling error which reflects the number of facilities tested out of the total, the representativeness of the tests of long term conditions and measurement error from inaccuracies in the stack monitoring and chemical analysis. The propagation of error approach used here assumes that the variability in the emissions from the sampled facilities is an indication of the possible uncertainty in the emissions from the whole class of facilities. While some of the variability is due to differences in the design and operation of the facilities, some also results from the various sources of uncertainty. It is impossible to know how much of the variability can be attributed to design/operation versus uncertainty, so this approach interprets all of the variability as an indication of the possible uncertainty. While this may imply an overestimate of the uncertainty, this is offset to some degree by the limitations of the database, such as the small n's for many classes, lack of testing during start-up and shutdown, use of short term testing to represent long term conditions, etc.

The total releases (R_{total}) are calculated by summing the releases across the 9 largest air sources (Ri) which account for over 90% of the total:

$$R_{Total} = \sum_{i=1}^{9} R_i \tag{1-6}$$

The emissions from each source are computed as the product of the emission factor and activity:

$$R_{Total} = \sum_{i=1}^{9} EF_i \times A_i \tag{1-7}$$

where

R_{Total} = Total Releases (g TEQ/year)

EF_i = Emission factor for source i (ng TEQ/kg)

A_i = Activity for source i (kg/year)

The emission factor is calculated on the basis of emission measurements that involve some error. Sampling error results from the fact, in general, only a small subset of the total facilities in each source class was tested. Measurement error is associated with stack sampling procedures and has been estimated to be +/- 30% for dioxins (U.S. EPA, 1990b). Lanier and Hendrix (2001) assessed the accuracy of Test Method 23 for stack measurements of PCDD and PCDFs. For determination of total PCDD/PCDF mass, the analysis found that RSD varied between about 6.3% and 20% for stack concentrations in the range of 2 to 27 ng/dscm. Although activity estimates also have uncertainty, it is assumed here that this is negligible compared to the uncertainty in the emission factor. The amount of error in estimating the releases from each source is assumed to be independent of each other. The variance in releases from each source is estimated using the variance of the emission factor data and treating the activity as a constant:

$$variance\ \ in\ R_{Total} = \sum_{i=1}^{9} variance\ \ in\ EF_i \times A_i^2 \quad (1\text{-}8)$$

Generally, the variance estimates for the emission factors were derived using the standard equation, i.e. $\Sigma(x - 0)^2/(n-1)$. However, in a few cases, some special considerations were necessary:

- The emission factor data for forest fires consisted of a series of chamber tests and field tests. Given the fundamental differences in the data from these two types of tests, it was not considered appropriate to combine them. Instead, the emission factor was estimated for each data set and averaged to get the best overall estimate:

$$EF = 0.5\left(EF_{field} + EF_{chamber}\right) \quad (1\text{-}9)$$

$$variance\ in EF = 0.5^2\left(variance\ in EF_{field} + variance\ in\ EF_{chamber}\right) \tag{1-10}$$

- In 2000, stack tests were available for all operating municipal waste incinerators and cement kilns burning hazardous waste. The total emissions for these two classes were estimated by summing the individual emissions from each facility. Thus, an emission-factor approach based on a subset of the facilities was not necessary. Because all facilities were tested, in theory, there is no sampling error. However, it is recognized that factors other than sampling error can contribute to the error in these estimates. Therefore, the variance for these sources were estimated and included in the propagation of error calculation.

Table 1-19 summarizes the results of this analysis. The analysis concludes that the total emissions sum to 2,100 g TEQ/year with a standard deviation of 1,300 g TEQ/year.

Frey and Zhao (2004) demonstrated that probabilistic methods can be used to evaluate uncertainties in emission inventories for benzene, formaldehyde, chromium, and arsenic. Accordingly, a probabilistic approach was also explored here as discussed below.

Probabilistic methods for evaluating uncertainty require developing distributions for the input variables. Frey and Zhao (2004) fit their emission factor data to parametric distributions using maximum likelihood estimation. This is a complex procedure and difficult to apply accurately to the emission factor data sets with low *n* values. Instead, all emission factors were assumed to have log normal distributions with means and standard deviations based on an arithmetic analysis of the data. Log normal distributions have been found to apply to many types of environmental data including emission factors (Frey and Zhao, 2004). A Monte Carlo analysis was conducted using the Crystal Ball program. A total of 10,000 simulations were run, producing a mean of 2,100 g TEQ and standard deviation of 1,100 g TEQ, which are very similar to the results of the propagation-of-error approach described above. Percentiles were estimated as 1,100 g TEQ for 10%, 1,800 g TEQ for 50%, and 3,300 g TEQ for 90%. These percentiles can be interpreted as the probability that the emissions will less than or equal to the specified amount.

Finally, further analysis is offered on the uncertainties associated with the forest fires. These uncertainties are especially important to evaluate because they are the largest source and have high uncertainty in the emission factor. As stated above, both chamber studies and field studies have been used to measure these emissions. The field data suggest an emission factor of

0.95 ng TEQ/kg, and the chamber data suggest an emission factor of 7.5 ng TEQ/kg. If the lower emission factor is used, the forest fires would have a release of 230 g TEQ, and the total releases across the 9 top sources would be 1,600 g TEQ. Similarly, if the higher emission factor is used, the forest fires would have a release of 1,800 TEQ, and the total releases across the nine top sources would be 3,200 g TEQ.

1.3.6.2. *Land Releases*

The 2000 land releases were dominated by backyard barrel burning which had releases of 1,900 g WHO_{98} TEQ (88% of the total) and the uncertainty analysis was limited to this one source. The releases from backyard barrel burning were based on a study by Lemieux (1997). Ash samples from the experiments were combined, resulting in two composite samples, one for recyclers (2,700 ng WHO_{98} TEQ_{DF} /kg ash) and one for nonrecyclers (620 ng WHO_{98} TEQ_{DF} /kg ash). The final emission factor was based on the average of these values (1,700 ng WHO_{98} TEQ_{DF} /kg ash). The limited data do not allow a statistical analysis such as done for the air releases. Instead a potential range of releases was estimated based on the lower and upper emission factor estimates. The activity estimate for 2,000 was 1.2 MMT. Combining this value with the lower emission factor yields a release estimate of 740 g WHO_{98} TEQ. Combining the activity with the higher emission factor yields a release estimate of 2,800 g WHO_{98} TEQ. Accordingly the potential range of releases is 740 to 2,800 g WHO_{98} TEQ. Relative to the average value (1,900 g WHO_{98} TEQ), the lower estimate is 62% less and the upper estimate is 46% more.

1.3.7. Relative Impact of Releases

When comparing national release estimates across sources, it should not be assumed that the magnitude of dioxin-like compound emissions is proportional to their impact on human health. Human exposure to dioxins occurs primarily via the diet. Therefore, factors such as the proximity of sources to food production areas and their location relative to wind direction may cause disproportionate impacts from emissions.

Table 1-1. Nomenclature for dioxin-like compounds

Term/symbol	Definition
CDD	Chlorinated dibenzo-*p*-dioxin, halogens substituted in any position
CDF	Chlorinated dibenzofuran, halogens substituted in any position
PCB	Polychlorinated biphenyl
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)
2,3,7,8	Halogen substitutions in the 2,3,7,8-positions
Congener	Any one particular member of the same chemical family (e.g., there are 75 congeners of CDDs)
Congener group	Group of structurally related chemicals that have the same degree of chlorination (e.g., there are eight congener groups of CDDs, MCDD through OCDD)
Isomer	Substances that belong to the same congener group (e.g., 22 isomers constitute the congener group of TCDDs)
Specific isomer	Isomers denoted by unique chemical notation (e.g., 2,4,8,9-tetrachlorodibenzofuran is referred to as 2,4,8,9-TCDF)

MCDD = monochlorinated.
OCDD = octachlorinated.

Source: Adapted from U.S. EPA (1989).

Table 1-2. TEF schemes for CDDs, CDFs, and PCBs

Compound	I-TEFs	WHO_{94}	WHO_{98}	WHO_{2005}
Chlorinated dibenzo-*p*-dioxins				
2,3,7,8-TCDD	1		1	1
1,2,3,7,8-PeCDD	0.5		1	1
1,2,3,4,7,8-HxCDD	0.1		0.1	0.1
1,2,3,6,7,8-HxCDD	0.1		0.1	0.1
1,2,3,7,8,9-HxCDD	0.1		0.1	0.1
1,2,3,4,6,7,8-HpCDD	0.01		0.01	0.01
OCDD	0.0001		0.0001	0.0003
Chlorinated dibenzofurans				
2,3,7,8-TCDF	0.1		0.1	0.1
1,2,3,7,8-PeCDF	0.05		0.05	0.03
2,3,4,7,8-PeCDF	0.5		0.5	0.3
1,2,3,4,7,8-HxCDF	0.1		0.1	0.1
1,2,3,6,7,8-HxCDF	0.1		0.1	0.1
1,2,3,7,8,9-HxCDF	0.1		0.1	0.1
2,3,4,6,7,8-HxCDF	0.1		0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01		0.01	0.01
1,2,3,6,7,8,9-HpCDF	0.01		0.01	0.01
OCDF	0.0001		0.0001	0.0003

Table 1-2. TEF schemes for CDDs, CDFs, and PCBs (continued)

Compound	I-TEFs	WHO_{94}	WHO_{98}	WHO_{2005}
Polychlorinated Biphenyls				
3,3',4,4'-TCB (PCB-77)		0.0005	0.0001	0.0001
3,4,4',5-TCB (PCB-81)			0.0001	0.0003
2,3,3',4,4'-PeCB (PCB-105)		0.0001	0.0001	0.00003
2,3,4,4',5-PeCB (PCB-114)		0.0005	0.0005	0.00003
2,3',4,4',5-PeCB (PCB-118)		0.0001	0.0001	0.00003
2',3,4,4',5-PeCB (PCB-123)		0.0001	0.0001	0.00003
3,3',4,4',5-PeCB (PCB-126)		0.1	0.1	0.1
2,3,3',4,4',5-HxCB (PCB-156)		0.0005	0.0005	0.00003
2,3',4,4',5,5'-HxCB (PCB-157)		0.0005	0.0005	0.00003
2,3',4,4',5,5'-HxCB (PCB-167)		0.00001	0.00001	0.00003
3,3',4,4',5,5'-HxCB (PCB-169)		0.01	0.01	0.03
2,2',3,3',4,4',5-HpCB (PCB-170)		0.0001		
2,2',3,4,4',5,5'-HpCB (PCB-180)		0.00001		
2,3,3',4,4',5,5'-HpCB (PCB-189)		0.0001	0.0001	0.00003

OCDF = octachlorodibenzofuran.
OCDD = octachlorinated.

Table 1-3. Municipal waste combustors[a]

Category[b]	Stack emission limit[c] (ng total CDD/CDF/dscm)	Effective date
New, large	13	September 20, 1994[d] June 19, 1996[e]
Existing, large With electrostatic precipitators as the APCD With dry scrubber/fabric filters as the APCD	 60 30	When SIPs are approved[f]
New, small	13	June 6, 2001[g]
Existing, small With electrostatic precipitators as the APCD With dry scrubber/fabric filters as the APCD	 60 30	When SIPs are approved[h]

[a]Air emission standards promulgated on December 19, 1995.
[b]Large = aggregate capacity $\geq$225 tons/day; small = aggregate capacity <225 tons/day.
[c]ng total CDD/CDF/dscm = nanograms total Cl_4–Cl_8 CDDs plus CDFs per dry standard cubic meter of stack gas volume, corrected to 7% O_2.
[d]Began construction on this date.
[e]Modified or upgraded on this date.
[f]When SIPs have been approved by EPA (approximately 3 years from the final rule, or 1998).
[g]For facilities constructed on or before this date.
[h]When SIPs have been approved by EPA (approximately 3 years from the final rule, or 2003).

APCD = air pollution control device.
SIP = State Implementation Plan.

Table 1-4. Hazardous waste combustors[a]

Source category	Standards for new sources[b]	Standards for existing sources[b]
Incinerators burning hazardous waste	For an incinerator with dry APCD and/or waste heat boiler: 0.11 ng I-TEQ/dscm For all other incinerators: 0.20 ng I-TEQ/dscm	For an incinerator with dry APCD and/or waste heat boiler: 0.20 ng I-TEQ/dscm, or 0.40 ng I-TEQ/dscm when PM control device operated >400°F For all other incinerators: 0.40 ng I-TEQ/dscm
Cement kilns burning hazardous waste	0.20 ng I-TEQ/dscm, or 0.40 ng I-TEQ/dscm when PM control device operated >400°F	0.20 ng I-TEQ/dscm, or 0.40 ng I-TEQ/dscm when PM control device operated >400°F
Lightweight aggregate kilns burning hazardous waste	0.20 ng I-TEQ/dscm, or rapid quench of combustion gas to below 400°F at kiln exit	0.20 ng I-TEQ/dscm, or rapid quench of combustion gas to below 400°F at kiln exit
Solid fuel boilers burning hazardous waste	Either CO of 100 ppmv or HC of 10 ppmv	Either CO of 100 ppmv or HC of 10 ppmv
Liquid fuel boilers burning hazardous waste	For a LFB with dry APCD: 0.40 ng I-TEQ/dscm. For all other LFBs: Either CO of 100 ppmv or HC of 10 ppmv	For a LFB with dry APCD: 0.40 ng I-TEQ/dscm. For all other LFBs: Either CO of 100 ppmv or HC of 10 ppmv
Hydrochloric acid production furnaces burning hazardous waste	Either CO of 100 ppmv or HC of 10 ppmv	Either CO of 100 ppmv or HC of 10 ppmv

[a]Air emission standards promulgated October 12, 2005.
[b]ng I-TEQ/dscm = nanogram I-TEQ per dry standard cubic meter of stack gas volume corrected to 7% O_2.

APCD = Air pollution control device (dry = dry scrubber or fabric filter).
CO = carbon monoxide continuously monitored.
HC = Total hydrocarbons continuously monitored.
LFB = Liquid fuel boiler.
PM = Particulate matter.

Table 1-5. Cement kilns not burning hazardous waste[a]

Existing cement kilns[b]	New cement kilns[b]
0.20 ng I-TEQ/dscm and temperature control <400EF at the APCD inlet 0.40 ng I-TEQ/dscm when PM control device operated >400EF	0.20 ng I-TEQ/dscm and temperature control <400EF at the APCD inlet 0.40 ng I-TEQ/dscm when PM control device operated >400EF

[a]Air emission standards promulgated on June 14, 1999.
[b]ng I-TEQ/dscm = nanograms I-TEQ per dry standard cubic meter of stack gas volume corrected to 7% O_2.

APCD = Air pollution control device.
PM = Particulate matter.

Table 1-6. Secondary aluminum smelters[a]

Process	Emission standard
Sweat furnace	0.8 ng I-TEQ/dscm stack gas corrected to 7% O_2
Thermal chip dryer	2.50 μg I-TEQ per MT of scrap charged to the dryer
Scrap dryer/delacquering kiln/decoating kiln	0.25 g I-TEQ per MT of scrap charged to the kiln
Scrap dryer/delacquering kiln/decoating kiln equipped with an afterburner	5.0 g I-TEQ per MT of scrap charged to the kiln

[a]Air emission standards promulgated on March 23, 2000.

MT = metric ton.

Table 1-7. Medical waste incinerators[a]

Category	Existing (ng $WHO_{2005}TEQ$/dscm)	New (ng $WHO_{2005}TEQ$/dscm)
Large	0.054	0.035
Medium	0.020	0.014
Small	0.013	0.013
Small rural	2.1	

[a]Federal Register, 2009.

Table 1-8. Pulp and paper mills[a]

Pollutant	Maximum 1-day wastewater discharge
Tetrachlorodibenzo-*p*-dioxin	<5 parts per quadrillion
Tetrachlorodibenzofuran	31.9 picograms per liter

[a]Effluent limitation guidelines promulgated on April 15, 1998.

Table 1-9. Commercial/Industrial solid waste incinerators[a]

Category	Existing (ng $WHO_{2005}TEQ$/dscm)	New (ng $WHO_{2005}TEQ$/dscm)
Incinerators	0.13	0.13
Energy Recovery Units - solids	0.059	0.011
Energy Recovery Units – liquid/gas	0.32	0.002
Waste Burning Kilns	0.0070	0.0030
Small, remote Incinerators	57	31

[a]Federal Register, 2011a.

Table 1-10. Sewage sludge incinerators[a]

Category	Existing (ng $WHO_{2005}TEQ$/dscm)	New (ng $WHO_{2005}TEQ$/dscm)
Multiple Hearth	0.32	0.0022
Fluidized Bed	0.10	0.0044

[a]Federal Register, 2011b.

Table 1-11. Industrial, commercial, and institutional boilers and process heaters[a]

Category	Existing (ng $WHO_{2005}TEQ$/dscm)	New (ng $WHO_{2005}TEQ$/dscm)
Coal Stoker	0.003	0.003
Coal Fluidized Bed	0.002	0.002
Pulverized Coal	0.004	0.003
Biomass Stoker/other	0.005	0.005
Biomass Fluidized Bed	0.02	0.02
Biomass Dutch Oven/Suspension Burner	0.2	0.2
Biomass Fuel Cells	4	0.003
Biomass Suspension/Grate	0.2	0.2
Liquid	4	0.002
Gas 2 (Other Process Gases)	0.08	0.08
Non-continental liquid	4	0.002

[a]Federal Register, 2011c.

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ.
WASTE INCINERATION												
Municipal solid waste incinerators												
1987	9,500								x			x
1995	1,200								x			x
2000	77								x			x
Hazardous waste incinerators												
1987	5								x			
1995	6								x			
2000	3								x			
Industrial boilers burning haz. waste												
1987	0.8								x			
1995	0.4								x			
2000	0.7								x			
Halogen acid furnaces burning haz. waste												
1987	0.3								x			
1995	0.3								x			
2000	0.3								x			

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Medical waste incinerators												
1987	2,700								x			
1995	510								x			
2000	400								x			
Human crematoria												
1987	0.2				0.1[a]							
1995	0.2				0.1[a]							
2000	0.3				0.1[a]							
Animal crematoria												
1987		3										
1995		4										
2000		4										
Sewage sludge incinerators												
1987	6								x			
1995	14								x			
2000	10								x			
Tire combustion												
1987		0.1							x			
1995		0.1							x			
2000		0.5							x			
Biogas combustion												
1987		0.2[a]										
1995		0.2[a]										
2000		0.2[a]										

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
POWER/ENERGY GENERATION												
Leaded gasoline, on-road												
1987	50											
Leaded gasoline, off-road												
1987		3										
Unleaded gasoline, on-road												
1987	5											
1995	6											
2000	7											
Unleaded gasoline, off road												
1987		0.2										
1995		0.3										
2000		0.4										
Diesel, on-road												
1987	51											
1995	55											
2000	64											
Diesel, off-road												
1987		19										
1995		20										
2000		23										

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Indoor residential wood burners												
1987	36			21								
1995	19			11								
2000	15			9								
Outdoor wood-fired boilers												
2000		9										
Industrial wood combustion												
1987	78											
1995	78											
2000	82											
Commercial and residential oil combustion												
1987	6											
1995	6											
2000	7											
Utility sector and industrial oil combustion												
1987	19											
1995	14											
2000	15											

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Waste oil combustion												
1987		0.6										
1995		0.7										
2000		0.7										
Industrial coal-fired utilities												
1987	51			17								
1995	60			18								
2000	70			22								
Industrial coal-fired boilers												
1987	48								x			
1995	46								x			
2000	41								x			
Residential coal combustion												
1987	10				0.1							
1995	5				0.1							
2000	3				<0.1							
OTHER HIGH TEMPERATURE SOURCES												
Cement kilns burning hazardous waste												
1987	120				4[a]				x			
1995	160				4[a]				x			
2000	19				3[a]				x			

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

	Air releases			Land releases			Water releases			Product releases		
Source	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ.**	**Q. Inv.**	**Prelim.**	**NQ**
Cement kilns not burning hazardous waste												
1987	13				<0.1				x			
1995	17				<0.1				x			
2000	17				<0.1				x			
Lightweight aggregate kilns												
1987	3[a]											
1995	2[a]											
2000	2											
Asphalt mixing plants												
1987	5[a]											
1995	5[a]											
2000	5[a]											
Petroleum refining catalyst regeneration plants												
1987	2								x			
1995	2								x			
2000	2								x			
Cigarette smoking												
1987	1											
1995	0.8											
2000	0.7											

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

	Air releases			Land releases			Water releases			Product releases		
Source	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ.**	**Q. Inv.**	**Prelim.**	**NQ**
Carbon reactivation furnaces												
1987	0.1											
1995	0.1											
2000	0.1											
Kraft black liquor recovery boilers												
1987	2											
1995	2											
2000	0.9											
Lime kilns												
2000	0.1											
Glass manufacturing												
1987	0.4[a]											
1995	0.4[a]											
2000	0.4[a]											
Automobile shredders and thermal APCDs at plating and painting facilities												
1987			x									
1995			x									
2000			x									

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
MINIMALLY CONTROLLED OR UNCONTROLLED COMBUSTION												
Combustion of landfill gas												
1987		2[a]										
1995		7[a]										
2000		22[a]										
Structural fires												
1987		24		260					x			
1995		18		200					x			
2000		16		180					x			
Vehicle fires—cars and other vehicles												
1987		39[a]		11[a]		x			x			
1995		29[a]		7[a]		x			x			
2000		24[a]		6[a]		x			x			
Landfill fires												
1987		1,300										
1995		1,300										
2000		1,300										
Forest and brush fires												
1987	180				18[a]							
1995	170				17[a]							
2000	730				73[a]							
Backyard burning												
1987	610			2,000								
1995	630			2,000								
2000	600			2,000								

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Residential yard burning												
1987	4				<0.1							
1995	5				<0.1							
2000	5				<0.1							
Land clearing debris burning												
1987		83			8							
1995		79			8							
2000		85			9							
Open burning of demolition/construction wood												
1987		22			240							
1995		22			240							
2000		22			240							
Fireworks, underground coal fires, open burning of energetic materials, PCBs, candles, oil spills												
1987			x			x						
1995			x			x						
2000			x			x						
Sugar cane burning												
1987		28			1							
1995		31			2							
2000		35			2							

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
METALLURGICAL PROCESSES												
Primary copper smelting and refining												
1987	0.3[a]											
1995	0.5[a]											
2000	0.5[a]											
Primary magnesium smelting and refining												
1987	13								x			
1995	13								x			
2000	8								x			
Primary nickel smelting and refining												
1987			x						x			
1995			x						x			
2000			x									
Primary titanium smelting and refining												
1987			x						x			
1995			x						x			
2000			x						x			
Secondary aluminum smelting												
1987	11											
1995	20											
2000	8											

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Secondary zinc production												
1987	4[a]											
1995	7[a]											
2000	7[a]											
Secondary copper smelting												
1987	990											
1995	270											
2000	0.9											
Secondary lead smelting												
1987	1											
1995	2											
2000	2											
Sinter production												
1987	33											
1995	28											
2000	24											
Coke production												
1987	10[a]											
1995	9[a]											
2000	8[a]											
Secondary ferrous metal smelting/refining												
1987	37											
1995	46											
2000	59											

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Ferrous foundries												
1987	13											
1995	19											
2000	16											
Aluminum foundries												
1987		0.3[a]										
1995		0.3[a]										
2000		0.3[a]										
Copper foundries												
1987	<0.1[a]											
1995	<0.1[a]											
2000	<0.1[a]											
Scrap electric wire recovery												
1987			x			x						
1995			x			x						
2000			x			x						
Drum and barrel reclamation furnaces												
1987	0.6					x						
1995	0.6					x						
2000	0.6					x						

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
CHEMICAL MANUFACTURING/PROCESSING SOURCES												
Bleached chemical pulp and paper mills												
1987				14			360					x
1995				2			28					x
2000				0.2			1					x
Stand-alone chlor-alkali plants												
1987												
1995	<0.1[a]						2[a]					
2000	<0.1[a]						2[a]					
Stand-alone vinyl chloride plants												
1987												
1995												
2000	0.6[a]						<0.1[a]					x
Complex chemical plants producing chlorine and a variety of chlorinated organics												
1987										33		
1995										29		
2000	5			1			25					x

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ.	Q. Inv.	Prelim.	NQ
Municipal wastewater treatment plants												
1987				62				13		3		
1995				120				12		18		
2000				50				15		7		
Residential septic systems												
1987					0.2							
1995					0.2							
2000					0.3							
Manufacturing of soaps, detergents, textiles, dyes, pigments, and inks												
1987			x									
1995			x									
2000			x									
All natural processes and sources, including ball clay, biotransformation, etc.												
1987			x			x			x			
1995			x			x			x			
2000			x			x			x			

Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_{DF}/year) (continued)

	Air releases			Land releases			Water releases			Product releases		
Source	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ.**	**Q. Inv.**	**Prelim.**	**NQ**
TOTALS												
1987	15,000	1,500		2,400	270		360	13		36		
1995	3,400	1,500		2,400	270		30	12		47		
2000	2,300	1,500		2,300	330		28	15		7		

[a]Results provided in I-TEQ.

x = Releases are possible during this year, but the data are insufficient to develop estimates.
Q. Inv. = Quantitative Inventory.
Prelim. = Preliminary.
NQ = Not quantified.
APCD = air pollution control device.
Blanks = No evidence that releases occur.

Table 1-13. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_p/year)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
RELEASES FROM COMMERCIAL PCB PRODUCTS												
PCB incineration			x						x			
Accidental fires, leaks, and spills			x			x			x			
CHEMICAL MANUFACTURING AND PROCESSING SOURCES												
Municipal wastewater treatment 1987 1995 2000				 51 78 19						 2 12 3		
COMBUSTION SOURCES												
Municipal waste combustors 1987 1995 2000		 7 15 15										
Industrial wood combustion			x									
Medical waste incineration 1987 1995 2000		 97 18 14										
Tire combustion			x									

Table 1-13. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_p/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Cigarette smoking												
1987		<0.1										
1995		<0.1										
2000		<0.1										
Sewage sludge incineration												
1987		0.4										
1995		1										
2000		0.7										
Backyard barrel burning												
1987	41			1								
1995	43			1								
2000	34			0.8								
Petroleum refining catalyst regeneration			x									
Hazardous waste incineration			x									
Power plants			x									
Forest fires						x						
1987		12										
1995		11										
2000		49										

Table 1-13. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_p/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**	**Q. Inv.**	**Prelim.**	**NQ**
METAL REFINING												
Iron ore sintering												
1987		4										
1995		3										
2000		3										
Copper smelting			x									
Aluminum smelting			x									
TOTAL												
1987	41	120		52						2		
1995	43	48		79						12		
2000	34	82		20						3		

x = Releases are possible during this year, but the data are insufficient to develop estimates.
Q. Inv. = Quantitative Inventory.
Prelim. = Preliminary.
NQ = Not quantified.
Blanks = No evidence that releases occur.

Table 1-14. Summary of CDD/CDF reservoir releases (g WHO_{98} TEQ_{DF})

Source	Air releases			Land releases			Water releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Soil reservoirs									
1987			x					5,000[a]	
1995			x					4,600[a]	
2000			x					4,300[a]	
Water, sediment, biota reservoirs									
1987			x			x			x
1995			x			x			x
2000			x			x			x
Product reservoirs									
1987			x			x			x
1995			x			x			x
2000			x			x			x

[a]Includes both urban and rural waters.
x = Releases are possible during this year, but the data are insufficient to develop estimates.
Q. Inv. = Quantitative Inventory.
Prelim. = Preliminary.
NQ = Not quantified.

Table 1-15. Summary of PCB reservoir releases (g WHO_{98} TEQ_{P})

Source	Air releases			Land releases			Water releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Soil reservoirs									
1987			x					200[a]	
1995			x					180[a]	
2000			x					170[a]	
Water, sediment, biota reservoirs									
1987			x			x			x
1995			x			x			x
2000			x			x			x
Product reservoirs									
1987			x			x			x
1995			x			x			x
2000			x			x			x

[a]Includes rural waters only.
x = Releases are possible during this year, but the data are insufficient to develop estimates.
Q. Inv. = Quantitative Inventory.
Prelim. = Preliminary.
NQ = Not quantified.

Table 1-16. Ranking of top five sources by year and media release

	1987 releases (g TEQ)	1995 releases (g TEQ)	2000 releases (g TEQ)
Air	Municipal waste—9,500 Medical waste—2,700 2° copper—990 Backyard barrel—610 Forest—180	Municipal waste incineration—1,200 Backyard barrel—630 Medical waste incineration—510 2° copper—270 Forest—170	Forest—730 Backyard barrel—600 Medical waste incineration—400 Industrial wood—82 Municipal waste incineration—77
Land	Backyard barrel—2,000 Structure fires—260 Municipal waste treatment—62 Residential wood—21 Coal utilities—17	Backyard barrel—2,100 Structure fires—200 Municipal waste treatment—120 Coal utilities—18 Residential wood—11	Backyard barrel—2,000 Structure fires—180 Municipal waste treatment—50 Coal utilities—22 Residential wood—9
Water	Paper mills—360	Paper mills—28 Chlor-alkali plants—2	Chlorinated organics—25 Chlor-alkali plants—2 Paper mills—1

Table 1-17. Amounts of CDDs/CDFs (g WHO_{98} TEQ_{DF}/year) contained in products in year manufactured

Product	1987	1995	2000
Bleached chemical wood pulp	500	40	0.6
Ethylene dichloride/vinyl chloride	NA	0.02	0.02
Chloranil[a]	64[b]	0.4[b]	1.2[b]
Pentachlorophenol	20,000	4,800	4,200
2,4 -Dichlorophenoxy acetic acid (2,4-D)[a]	33	29	NA
TOTAL	21,000	4,900	4,200

[a]Only 2,4-D is considered to be an environmental release.
[b]Units are I-TEQ.

NA = not available.

Table 1-18. Trend analyses based on quantitative inventory[a]

	Releases (g WHO_{98} TEQ)			Percent change		
	1987	**1995**	**2000**	**1987 to 1995**	**1995 to 2000**	**1987 to 2000**
Air	15,000	3,400	2,300	−77	−32	−85
Land	2,400	2,500	2,300	+4	−8	−4
Water[b]	360	28	1	−92	−96	−100
Product	36	47	7	+31	−85	−81
Total	18,000	6,000	4,600	−67	−23	−74

[a]These trends are based on the quantitative inventory only, i.e., they do not include the sources classified as preliminary or unquantifiable. **Some of the preliminary sources are potentially very large and if confirmed could significantly change the trend observations.**

[b]Water releases are based on bleached pulp and paper plants only because this is only source covered in all three reference years.

Table 1-19. Uncertainty analysis for top nine air sources in 2000

	Activity (kg)	Emission factor (ng WHO_{98}-TEQ/kg)			Releases (g WHO_{98}-TEQ)	
	Total	mean	*n*	SD	Total	SD
Forest fires	2.44×10^{11}	3	13	4.7	730	1,100
Backyard barrel burning	7.79×10^{9}	77	5	53	600	410
Medical waste						
Uncontrolled	1.98×10^{8}	1,900	7	1,600	380	320
Controlled	4.03×10^{8}	51	13	81	20	33
Municipal waste combustion			105		77	27
Coal fired utility boilers	8.94×10^{11}	0.078	11	0.2	70	130
Industrial wood						
Salt laden	8.0×10^{8}	15	5	11	12	8.9
Nonsalt laden	1.16×10^{11}	0.6	9	0.6	70	66
Diesel on-road vehicles	1.19×10^{11}[a]	540[b]	7	240[b]	64	29
Cement kilns						
Burning haz waste			22		19	7
Not burning haz waste	6.37×10^{10}	0.27	13	0.9	17	55
Industrial coal-fired boilers	5.92×10^{10}	0.7	15	1.3	41	78
Total releases					2,100	1,300

[a]Units are L.
[b]Units are pg WHO_{98}-TEQ/L.

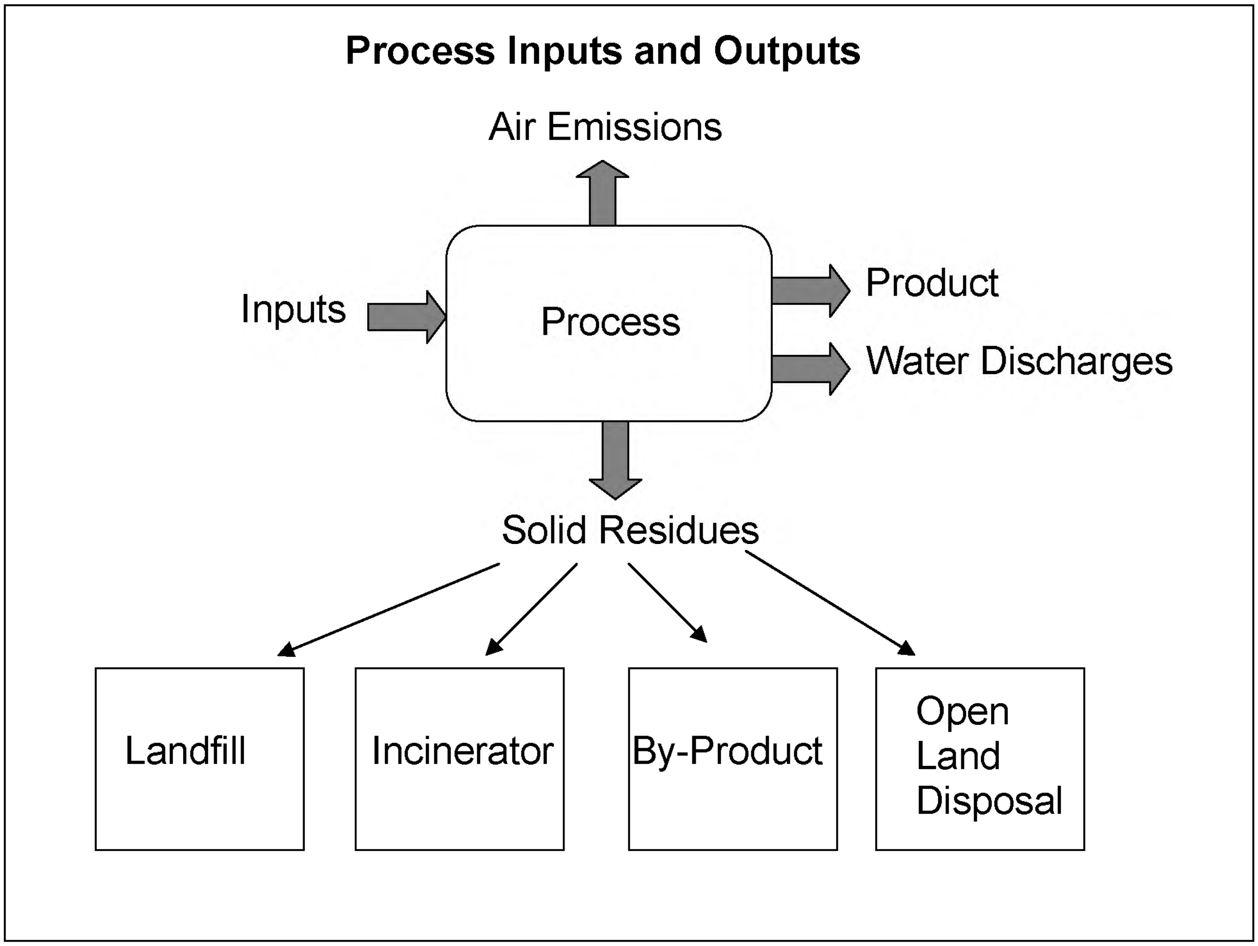


Figure 1-1. Process inputs and outputs.

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

This chapter has not been updated because it is not critical to the inventory and may be best presented elsewhere. Accordingly, any future updates to this chapter will be pursued independently from the inventory.

3. COMBUSTION SOURCES OF CDDS/CDFS: WASTE INCINERATION

3.1. MUNICIPAL WASTE COMBUSTION

3.1.1. Air Releases

More information was available for the municipal waste incinerators than any other source, allowing a detailed approach for estimating the total emissions. Stack test data were available for 11 of 111 facilities in 1987, 27 of 125 facilities in the 1995, and 78 of 105 facilities in 2000. These data were used to develop emission factors for over 20 design classes based on the combination of furnace type and air pollution controls. Additionally, a complete list of all facilities operating in the reference years and their activity levels were available. Releases from the tested facilities were derived directly from the stack tests, and the releases from the untested facilities were derived by assigning it an emission factor and multiplying by the activity. Finally, the total releases for each reference year were estimated by summing the releases from each facility operating in that year.

This approach is a modification of the approach used in the 2006 report. Emission factors were changed for a few design classes to make them more consistent, and new tables were developed for each reference year that list each facility and its emission factor, activity level, and emission rate (see Tables 3-1, 3-2, and 3-3). This led to some minor changes in total emissions.

The releases for the year 2000 were also estimated using the UNEP (2005) emission factors:

- Low technology, no APCD—35,000 ng I-TEQ/kg
- Controlled, minimal APCD—350 ng I-TEQ/kg
- Controlled, good APCD—30 ng I-TEQ/kg
- High technology, sophisticated APCD—0.5 ng I-TEQ/kg

The emission factor for controlled facilities with good APCDs (30 ng I-TEQ/kg) was applied to all small incinerators (defined as those with operating capacities less than 250 tons/day and totaling 2.6 million tons in 2000), and the emission factor for high technology facilities with sophisticated APCDs (0.5 ng I-TEQ/kg) was applied to all large facilities (defined as those with operating capacities greater than 250 tons/day and totaling 27 million tons in 2000). This approach yields a release estimate of 92 g I-TEQ/year, which is comparable to the 69 g I-TEQ_{DF}/year estimate reported here based on adding emissions of each facility.

3.1.2. Water Releases

Some municipal waste combustors use wet scrubbers to treat emissions. Water discharges may be associated with such devices. Some of these facilities have water treatment systems that reduce particulate levels (and associated dioxins) prior to discharge. No information was found to estimate the magnitude of CDD/CDF releases from these devices. Accordingly, releases are possible, but estimates could not be made (Not quantifiable).

3.1.3. Solid Residue Releases

In the United States, all municipal waste combustor ash (except the portion used in products—see discussion below) is disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a release to the open environment and is not included in the source inventory. However, for informational purposes and when sufficient information is available, this document provides estimates of the amounts of ash landfilled. The discussion below presents estimates of the amount of dioxin in municipal waste ash sent to landfills.

Municipal waste combustors create solid residues in the form of fly ash, which is collected from the stack by APCDs, and bottom ash, which is discharged directly from the combustor. As discussed in EPA (2006), a variety of studies have measured dioxin levels in municipal waste combustor ash from the United States. Only two of these provided congener data allowing TEQ calculations:

- Ashes from five state-of-the-art municipal waste combustor facilities located in different regions of the United States were analyzed for all 2,3,7,8-substituted CDDs/CDFs. The TEQ levels in the ash (fly ash mixed with bottom ash) ranged from 106 to 466 ng I-TEQ_{DF}/kg, with a mean value of 258 ng I-TEQ_{DF}/kg CDFs (U.S. EPA, 1990a).
- Washington State Department of Ecology (1998) reported CDD/CDF congener data for ash and other solid residuals from three municipal incinerators (Fort Lewis, Bellingham [municipal plus medical wastes], and Spokane). The data were compiled and evaluated to determine a total I-TEQ concentration and loading. The results showed fly ash ranging from 0.51 to 4.98 µg I-TEQ/kg, bottom ash ranging from 0.00 to 0.2 µg I-TEQ/kg, and mixed ash ranging from 0.038 to 0.163 µg I-TEQ/kg.

EPA (2006) also summarized municipal waste combustor ash information from a variety of studies conducted in other countries, with two reporting TEQ calculations:

- Kobylecki et al. (2001) analyzed the reduction of dioxins in fly ash by pelletizing the ash and reburning the pellets in a laboratory-scale bubbling fluidized-bed furnace. Fly ash for the test input material was collected from a fly ash filter vessel during 4 days of municipal waste combustor operation. The total TEQ value derived by Kobylecki was 862 ng I-TEQ_{DF}/kg of fly ash.
- Sakai et al. (2001) analyzed the levels of dioxins and PCBs in fly ash and bottom ash from a newly constructed municipal waste combustor in Japan. TEQ values derived from the data give a total of 423 ng I-TEQ_{DF}/kg for fly ash and 10.5 ng I-TEQ_{DF}/kg for bottom ash for dioxins and 31.6 ng I-TEQ_{DF}/kg for fly ash and 0.85 ng I-TEQ_{DF}/kg for bottom ash for PCBs.

UNEP (2005) provided emission factors for fly ash ranging from 15 to 500 μg I-TEQ/MT of municipal solid waste burned and emission factors for bottom ash ranging from 1.5 to 75 μg I-TEQ/MT of municipal solid waste burned. For municipal waste combustors with controlled combustion and good APCD (this class would be typical of many of the U.S. facilities), the recommended values were 200 μg I-TEQ/MT of municipal solid waste burned for fly ash and 7 μg I-TEQ/MT of municipal solid waste burned for bottom ash.

Given the very limited data on TEQ levels in ash from U.S. facilities, it was decided to use the UNEP (2005) default recommendations as follows: the UNEP recommendations for municipal waste combustors with controlled combustion and minimal APCDs (200 μg I-TEQ/MT of municipal solid waste burned for fly ash and 7 μg I-TEQ/MT of municipal solid waste burned for bottom ash) were assumed to apply to 1987. Extensive improvements in APCDs (including reductions in the use of hot-sided electrostatic precipitators ESPs) occurred from 1987 to 1990. So reductions would also be expected in the dioxin content of the ash. Thus, the UNEP recommendations for municipal waste combustors with controlled combustion and good APCDs (15 μg I-TEQ/MT of municipal solid waste burned for fly ash and 1.5 μg I-TEQ/MT of municipal solid waste burned for bottom ash) were assumed to apply to 1995 and 2000. These assumptions are summarized below:

- 1987—200 ng I-TEQ/kg of municipal solid waste burned for fly ash and 7 ng I-TEQ/kg of municipal solid waste burned for bottom ash

- 1995—15 ng I-TEQ/kg of municipal solid waste burned for fly ash and 1.5 ng I-TEQ/kg of municipal solid waste burned for bottom ash
- 2000—15 ng I-TEQ/kg of municipal solid waste burned for fly ash and 1.5 ng I-TEQ/kg of municipal solid waste burned for bottom ash

Multiplying the emission factors by the total municipal waste activity levels, yielded the following estimates of amount of dioxin in landfilled ash:

- 1987—2,800 g I-TEQ
- 1995—490 g I-TEQ
- 2000—490 g I-TEQ

As indicated earlier, in the United States, all municipal waste combustor ash (except the portion used in products—see discussion below) is disposed in permitted landfills and, therefore, not included in the source inventory.

The amount of ash generated by municipal waste incineration is not directly used in the procedure described above to estimate the amount of dioxin in landfilled ash. However, this may be of interest and is estimated here for informational purposes only. An estimated 7 MMT of total ash (bottom ash plus fly ash) were generated by municipal waste combustors in 1992 (telephone conversation between J. Loundsberry, EPA Office of Solid Waste, and L. Brown, Versar, Inc., February 24, 1993). EPA indicated that 2 to 5 MMT of total ash were produced annually in the late 1980s from municipal waste combustors, with fly ash comprising 5 to 15% of the total (U.S. EPA, 1991). UNEP (2005) indicates that the amount of fly ash generated per ton of municipal solid waste is typically 1−2%, and the amount of bottom ash generated per ton of municipal solid waste is approximately 10−20%. The amounts of ash generated were calculated using the midpoints of these ranges:

- 1987—The total municipal solid waste burned was estimated as 13.7 billion kg (this implies that 0.2 billion kg of fly ash and 2.1 billion kg of bottom ash were generated).
- 1995—The total municipal solid waste burned was estimated as 29.8 billion kg (this implies that 0.4 billion kg of fly ash and 4.5 billion kg of bottom ash were generated).

- 2000—The total municipal solid waste burned was estimated as 29.4 billion kg (this implies that 0.4 billion kg of fly ash and 4.4 billion kg of bottom ash were generated).

3.1.4. Products

The primary purpose of municipal waste combustors is waste disposal rather than the manufacture of products. However, some municipal waste combustor ash has been used in road-building materials (UNEP, 2005). The concentration of CDD/CDFs in these products would be a fraction of the level found in the original residues. For example, if the product contained 1% municipal waste combustor residues, the CDD/CDF concentration would be 1% of the level found in the original residue. No information could be found on the residue content of these products. Similarly, no information could be found on the quantity of ash going into such products. It is possible that the ash is tightly bound to the construction materials, reducing the chance of release to the open environment. However, no data could be found on this issue. Accordingly, releases are probably small, but estimates could not be made (Not quantifiable).

3.1.5. Release Summary

The inventory decision criteria and release estimates to all media are summarized below.

Inventory Decision Criteria for Municipal Waste Incinerators				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Municipal Waste Incinerators
Air Releases
Emission Factors • 1987—Table 3-1. • 1995—Table 3-2. • 2000—Table 3-3.
Activity Levels • 1987—Table 3-1 (overall total is 13.7 billion kg of waste). • 1995—Table 3-2 (overall total is 29.8 billion kg of waste). • 2000—Table 3-3 (overall total is 29.4 billion kg of waste).
Releases • 1987—Table 3-1. Total releases were 9,500 g WHO_{98} TEQ_{DF}/yr (8,500 g I-TEQ_{DF}/yr). • 1995—Table 3-2. Total releases were 1,200 g WHO_{98} TEQ_{DF}/yr (1,100 g I-TEQ_{DF}/yr). • 2000—Table 3-3. Total releases were 77 g WHO_{98} TEQ_{DF}/yr (69 g I-TEQ_{DF}/yr).
Water Releases
Water releases are possible, but data are insufficient to make quantitative estimates (Not quantifiable).
Solid Residue Releases
All municipal waste combustor ash (except the portion used in products—see below) is disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a release to the open environment and is not included in the source inventory.
Products
Product releases are possible, but data are insufficient to make quantitative estimates (Not quantifiable).

3.2. HAZARDOUS WASTE INCINERATION

Hazardous wastes are burned in a variety of situations and are covered in a number of different sections in this report.

- Hazardous waste is burned in facilities dedicated to burning this type of waste. Most of these dedicated facilities are located on site at chemical manufacturing facilities and burn only the waste associated with their on-site industrial operations. Hazardous waste is also burned at dedicated facilities located off site. These facilities accept waste from multiple sources. On- and off-site dedicated hazardous waste burning facilities are addressed in Section 3.2.1.
- Hazardous waste is also burned in industrial boilers and furnaces that are permitted to burn the waste as supplemental fuel. These facilities have significantly different furnace designs and operations than those of dedicated hazardous waste incinerators (HWIs). They are discussed in Section 3.2.2.

- Hazardous waste is also burned in halogen acid furnaces (HAFs), in which halogen acids (such as HCl) may be produced from halogenated secondary materials. These facilities are discussed in Section 3.2.3.
- A number of cement kilns and lightweight aggregate kilns are also permitted to burn hazardous waste as auxiliary fuel. These are discussed separately in Section 5.1.
- Mobile HWIs are typically used for site cleanup at Superfund sites. These units can be transported from one location to another and operate for a limited duration at any given location. Due to a lack of information about these facilities, they are not included in this inventory.

3.2.1. Dedicated HWIs

3.2.1.1. *Air Releases*

No changes were made in the air-release estimates reported in U.S. EPA (2006). Where feasible, this document subdivides the combustors in each source category into design classes judged to have similar potential for CDD/CDF emissions. However, this would not have been useful for dedicated HWIs because information was lacking about the amount of waste burned in each of the design classes. Additionally, all HWI designs achieve excellent combustion efficiency using high temperatures and long residence times, suggesting that little difference in emission factors would be observed among the design classes. Minor changes in design and operating procedures would be expected in 2000 due to the stricter emission limits that became effective at that time. Therefore, the strategy used to develop emission factors for HWIs was to assume that the emission tests conducted prior to 2000 represented facilities in operation during the reference years 1987 and 1995 and the emission tests conducted in 2000 represented the facilities operating in 2000.

The emission factors were developed using stack test data from a database compiled by the EPA Office of Solid Waste (OSW). This database summarizes the results of stack testing for CDDs/CDFs at a number of HWIs between 1993 and 2000 (U.S. EPA, 2002b). For the purposes of estimating emissions in 1995, an emission factor was developed using data from 17 HWIs tested between 1993 and 1996. For the purposes of estimating emissions in 2000, an emission factor was developed using data from 10 HWIs tested in 2000 (a total of 22 HWIs were tested in 2000, but flue gas flow rates were available for only 10 of these incinerators). For the purposes of estimating emissions in 1987, the emission factor derived for 1995 was assumed to apply to

1987. The 1987 activity estimate is from Dempsey and Oppelt (1993), and the 1995/2000 estimate is based on Federal Register (1996).

The emission factors assumed here were in the range of 2−4 ng I-TEQ/kg, which falls in between the values recommended by UNEP (2005) for the top two performing classes:

- Low technology, no APCD—35,000 ng I-TEQ/kg
- Controlled, minimal APCD—350 ng I-TEQ/kg
- Controlled, good APCD—10 ng I-TEQ/kg
- High technology, sophisticated APCD—0.75 ng I-TEQ/kg

3.2.1.2. *Water Releases*

Many HWIs use wet scrubber systems, which can have water discharges. However, no information was found to support release estimates (Not quantifiable).

3.2.1.3. *Solid Residue Releases*

EPA (1987) contains limited data on ash generated from hazardous waste incineration. The study indicates that the mean concentrations of CDDs and CDFs from an HWI with an afterburner were 538 μg/kg and 2,853 μg/kg, respectively (Table 3-8 in U.S. EPA, 1987). Specific data for congeners and for ash quantities were not provided. Accordingly, quantitative estimates cannot be made about amounts of CDD/CDFs in solid residues from dedicated HWIs. In the United States, all HWI ash is disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a true release to the open environment and is not included in the source inventory.

3.2.1.4. *Products—None*

3.2.1.5. *Release Summary*

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Dedicated HWIs				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Dedicated HWIs
Air Releases
Emission Factors • 1987—3.9 ng WHO_{98} TEQ_{DF}/kg (3.8 ng I-TEQ_{DF}/kg) of waste feed. • 1995—3.9 ng WHO_{98} TEQ_{DF}/kg (3.8 ng I-TEQ_{DF}/kg) of waste feed. • 2000—2.1 ng WHO_{98} TEQ_{DF}/kg (2.1 ng I-TEQ_{DF}/kg) of waste feed.
Activity Levels • 1987—1.3 billion kg. • 1995—1.5 billion kg. • 2000—1.5 billion kg.
Releases • 1987—5 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 1995—6 g WHO_{98} TEQ_{DF} (5.7 g I-TEQ_{DF}). • 2000—3 g WHO_{98} TEQ_{DF} (3 g I-TEQ_{DF}).
Water Releases
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).
Solid Residue Releases
Ash is landfilled, so it is not considered an environmental release.
Products
None.

3.2.2. Industrial Boilers and Furnaces Burning Hazardous Waste

3.2.2.1. *Air Releases*

The emission factors for industrial boilers and furnaces burning hazardous waste were derived from test data for three facilities presented in the OSW database. Minor changes in design and operating procedures would be expected in 2000 due to the stricter emission limits that became effective at that time. Therefore, the strategy used to develop emission factors for these facilities was to assume that the emission tests conducted prior to 2000 represented facilities in operation during the reference years 1987 and 1995 and the emission tests conducted in 2000 represented the facilities operating in 2000. The activity level used in US EPA, 2006 (derived from survey data in Dempsey and Oppelt, 1993 and other OSW data) for 2000 was changed from 1.5 to 0.6 billion kg based on the assumption that no change occurred from 1995. As a result, minor changes were also made in the air-release estimate for reference year 2000.

3.2.2.2. *Water Releases*

Some industrial boilers use wet scrubber systems, which can have water discharges. However, no information was found to support release estimates (Not quantifiable).

3.2.2.3. *Solid Residue Releases*

Because these facilities are typically burning liquid waste, little ash would be generated.

3.2.2.4. *Products—None*

3.2.2.5. *Release Summary*

The releases are summarized below:

Inventory Decision Criteria for Industrial Boilers and Furnaces Burning Hazardous Waste				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Industrial Boilers and Furnaces Burning Hazardous Waste
Air Releases
Emission Factors • 1987—0.65 ng WHO_{98} TEQ_{DF}/kg (0.64 ng I-TEQ_{DF}/kg) of waste feed. • 1995—0.65 ng WHO_{98} TEQ_{DF}/kg (0.64 ng I-TEQ_{DF}/kg) of waste feed. • 2000—1.2 ng WHO_{98} TEQ_{DF}/kg (1.2 ng I-TEQ_{DF}/kg) of waste feed.
Activity Levels • 1987—1.2 billion kg. • 1995—0.6 billion kg. • 2000—0.6 billion kg.
Releases • 1987—0.8 g WHO_{98} TEQ_{DF} (0.8 g I-TEQ_{DF}). • 1995—0.4 g WHO_{98} TEQ_{DF} (0.4 g I-TEQ_{DF}). • 2000—0.7 g WHO_{98} TEQ_{DF} (0.7 g I-TEQ_{DF}).
Water Releases
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).
Solid Residue Releases
None.
Products
None.

3.2.3. Halogen Acid Furnaces Burning Hazardous Waste

3.2.3.1. *Air Releases*

No changes were made to the air-release estimates. The emission factors for halogen acid furnaces (HAFs) burning hazardous waste were derived from the same OSW database used for dedicated HWIs. For the purposes of estimating emissions in 2000, an emission factor was developed using data from two HAFs tested in 2000. For the purposes of estimating emissions in 1987 and 1995, the emission factor derived for 2000 was assumed to apply to the earlier years. The activity estimate was based on survey data provided by OSW for 2000 and assumed to be also representative of the earlier years.

3.2.3.2. *Water Releases*

No information was found to support release estimates.

3.2.3.3. *Solid Residue Releases*

Because these facilities are typically burning liquid waste, no ash would be generated.

3.2.3.4. *Products—None*

3.2.3.5. *Release Summary*

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Halogen Acid Furnaces Burning Hazardous Waste				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Halogen Acid Furnaces Burning Hazardous Waste
Air Releases
Emission Factors • 1987—0.84 ng WHO_{98} TEQ_{DF}/kg (0.80 ng I-TEQ_{DF}/kg) of waste feed. • 1995—0.84 ng WHO_{98} TEQ_{DF}/kg (0.80 ng I-TEQ_{DF}/kg) of waste feed. • 2000—0.84 ng WHO_{98} TEQ_{DF}/kg (0.80 ng I-TEQ_{DF}/kg) of waste feed.
Activity Levels • 1987—376 million kg. • 1995—376 million kg. • 2000—376 million kg.
Releases • 1987—0.3 g WHO_{98} TEQ_{DF} (0.3 g I-TEQ_{DF}). • 1995—0.3 g WHO_{98} TEQ_{DF} (0.3 g I-TEQ_{DF}). • 2000—0.3 g WHO_{98} TEQ_{DF} (0.3 g I-TEQ_{DF}).
Water Releases
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).
Solid Residue Releases
None.
Products
None.

3.3. MEDICAL WASTE INCINERATION

3.3.1. Air Releases

Changes were made to the emission factors. The U.S. EPA, 2006 report divided the uncontrolled class into two subclasses and the controlled class into three subclasses. Some of these classes had very few tested facilities, and the range of emission factors overlapped between subclasses. Thus, it was decided to combine these classes into one emission factor for uncontrolled facilities (1,870 ng WHO_{98} TEQ/kg, 1,760 ng I-TEQ/kg) based on testing at seven facilities and one for controlled facilities (51 ng WHO_{98} TEQ/kg, 50 ng I-TEQ/kg) based on testing at 12 facilities. For comparison purposes, the UNEP (2005) emission factor recommendations are provided below:

- Uncontrolled, batch, no APCD—40,000 ng I-TEQ/kg
- Controlled, batch, minimal APCD—3,000 ng I-TEQ/kg
- Controlled, batch, good APCD—525 ng I-TEQ/kg
- Controlled, continuous, excellent APCD—1 ng I-TEQ/kg

Activity estimates are based on survey data summarized in U.S. EPA, 2006. Table 3-4 shows the activities and release estimates for each year. These changes resulted in small increases in total releases compared to the original values reported in U.S. EPA, 2006.

3.3.2. Water Releases

Some medical waste incinerators use wet scrubber systems, which can have water discharges. However, no information was found to support release estimates (Not quantifiable).

3.3.3. Solid Residue Releases

In the United States, all ash from medical waste incinerators is disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a true release to the open environment and is not included in the source inventory. However, for informational purposes, the discussion below presents estimates of the amount of dioxin in landfilled ash.

Fiedler et al. (2002) tested a hospital waste incinerator in Thailand. The furnace had a static grate and was equipped with a secondary combustion chamber and two afterburners. The flue gases passed over an alkaline water bath before being discharged through a flue stack. Overall, the plant appeared poorly designed and poorly maintained. Bottom ash concentrations of 1,390 and 1,980 ng -TEQ/kg were found. The authors suggest the high results were due to the poor combustion conditions in the primary chamber and the practice of leaving the bottom ashes overnight in the chamber to slowly cool down.

As indicated above, emission testing data could be located for only one facility. The poor condition of this facility suggests it is not representative of U.S. facilities. UNEP (2005) suggests emission factors ranging from 150 to 920 ng I-TEQ/kg of waste burned (for combined bottom ash and fly ash) for controlled facilities. The average of this range is assumed for all reference years: 530 ng I-TEQ_{DF}/kg of waste. These UNEP recommendations are not linked to specific references and appear to represent the professional judgment and consensus among the authors. It is unknown how representative this emission factor is of U.S. facilities. Accordingly, it is regarded as preliminary.

The amounts of dioxin in landfilled ash were estimated by multiplying the emission factor by the activity level:

- 1987—760 g $I\text{-}TEQ_{DF}$
- 1995—410 g $I\text{-}TEQ_{DF}$
- 2000—320 g $I\text{-}TEQ_{DF}$

Because the ash is landfilled, it is not considered a release to the open environment and is not included in the source inventory.

The total amount of landfilled ash is not directly used in the calculation above. However, it may be of interest and is provided below for information purposes only. The estimates were generated by assuming that the combined fly and bottom equals 20% of the waste feed (UNEP, 2005). This yields the following estimates:

- 1987—0.28 billion kg
- 1995—0.15 billion kg
- 2000—0.12 billion kg

3.3.4. Products—None

3.3.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Medical Waste Incinerators				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Medical Waste Incinerators
Air Releases
Emission Factors • 1987—Table 3-4. • 1995—Table 3-4. • 2000—Table 3-4.
Activity Levels • 1987—Table 3-4. • 1995—Table 3-4. • 2000—Table 3-4.
Releases • 1987—2,700 g WHO_{98} TEQ_{DF}/yr (2,600 g I-TEQ_{DF}/yr). • 1995—510 g WHO_{98} TEQ_{DF}/yr (490 g I-TEQ_{DF}/yr). • 2000—400 g WHO_{98} TEQ_{DF}/yr (380 g I-TEQ_{DF}/yr).
Water Releases
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).
Solid Residue Releases
The ash is landfilled so it is not considered an environmental release.
Products
None.

3.4. CREMATORIA

3.4.1. Human Crematoria

3.4.1.1. *Air Releases*

No changes were made to the air-release estimates. The emission factor was derived on the basis of testing at two U.S. facilities and assumed to apply to all reference years. It corresponds to the low end of the range recommended by UNEP (2005):
400 ng I-TEQ/cremation for facilities with optimal control, 10,000 ng I-TEQ/cremation for facilities with medium control, and 90,000 ng I-TEQ/cremation for facilities with no control.
Activity information was derived from CANA (2006).

3.4.1.2. *Water Releases*

These facilities do not use wet scrubbers, and there are no other identifiable water releases associated with their operation.

3.4.1.3. *Solid Residue Releases*

No information was found on the disposition of cremation ash. It is assumed here that all of it is eventually released to the open environment.

UNEP (2005) recommends an ash emission factor of 2,500 ng I-TEQ/cremation for facilities with medium or optimal control. The CDD/CDF concentrations in the bottom ashes collected from a two-chamber crematory in Thailand were 44 and 48 ng I-TEQ/kg of bottom ash (UNEP, 2005; Fiedler et al., 2002). Based on the average of these tests, a concentration of 46 ng I-TEQ/kg of bottom ash is assumed for each reference year. This facility appears to have a similar design to U.S. facilities. However, the emission factor was assigned a preliminary rating because it is based on testing at only one facility.

The total bottom ash generated was estimated by multiplying the number of bodies cremated per year (CANA, 2006), 5.5% ash content (Forbes et al., 1953), and 70 kg (average adult body weight). This yields the following estimates:

- 1987—1.24 million kg
- 1995—1.88 million kg
- 2000—2.42 million kg

The solid residue releases were estimated by multiplying the ash concentration by the ash activity level.

3.4.1.4. *Products—None*

3.4.1.5. *Release Summary*

The inventory decision criteria and releases are summarized below. The ash is typically disposed in landfills and therefore not considered an environmental release.

Inventory Decision Criteria for Human Crematoria				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		No	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		P	

Human Crematoria
Air Releases
Emission Factors • 1987—450 ng WHO_{98} TEQ_{DF}/body cremated (430 ng I-TEQ_{DF}/body cremated). • 1995—450 ng WHO_{98} TEQ_{DF}/body cremated (430 ng I-TEQ_{DF}/body cremated). • 2000—450 ng WHO_{98} TEQ_{DF}/body cremated (430 ng I-TEQ_{DF}/body cremated).
Activity Levels • 1987—A total of 323,371 cremations were performed. • 1995—A total of 488,224 cremations were performed. • 2000—A total of 629,362 cremations were performed.
Releases • 1987—0.2 g WHO_{98} TEQ_{DF} (0.1 g I-TEQ_{DF}). • 1995—0.2 g WHO_{98} TEQ_{DF} (0.2 g I-TEQ_{DF}). • 2000—0.3 g WHO_{98} TEQ_{DF} (0.3 g I-TEQ_{DF}).
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—46 ng I-TEQ/kg of ash (Preliminary). • 1995—46 ng I-TEQ/kg of ash (Preliminary). • 2000—46 ng I-TEQ/kg of ash (Preliminary).
Activity Levels • 1987—1.24 million kg ash. • 1995—1.88 million kg ash. • 2000—2.42 million kg ash.
Releases • 1987—0.1 g I-TEQ_{DF} (Preliminary). • 1995—0.1 g I-TEQ_{DF} (Preliminary). • 2000—0.1 g I-TEQ_{DF} (Preliminary).
Products
None.

3.4.2. Animal Crematoria

3.4.2.1. *Air Releases*

Minor changes were made in how these air releases were estimated. For destruction of animal carcasses, UNEP (2005) recommends emission factors of 5 ng I-TEQ/kg for state-of-the-art facilities, 50 ng I-TEQ/kg for updated facilities, and 500 ng I-TEQ/kg for uncontrolled facilities. As described in EPA, 2006, only one U.S. facility emission test could be located. This facility had very low emissions and may not be representative of most facilities. The mid-range value recommend by UNEP was judged to more likely represent typical U.S. facilities. Therefore, this emission factor was assumed to apply to each of the reference years: 50 ng I-TEQ_{DF}/kg of animal cremated. Based on the limited test data and questions about its representativeness, this emission factor is considered a preliminary estimate.

As part of the 2000 inventory, OAQPS (U.S. EPA, 2002b) calculated a national animal cremation activity level estimate of 81.9 million kg/year for reference year 2000. Assuming that the fraction of the population owning pets and the fraction of pets cremated stay reasonably constant, this value can be extrapolated to the other reference years by assuming that animal cremation rates are proportional to the human population. The following U.S. population estimates were used in this exercise: 1987—242 billion, 1995—263 billion, and 2000—291 billion. The data for each reference year are presented below:

- 1987—68 million kg/year.
- 1995—74 million kg/year
- 2000—81.9 million kg/year

3.4.2.2. *Water Releases—None*

3.4.2.3. *Solid Residue Releases*

All ash from these facilities is assumed to be disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a true release to the open environment and is not included in the source inventory. However, for informational purposes, the discussion below presents estimates of the amount of dioxin in landfilled ash.

As indicated above, emission testing data could be located for only one facility. No bottom ash testing was reported for this facility. It has a similar design to the human cremation facility in Thailand where testing found 44 and 48 ng I-TEQ/kg of bottom ash (UNEP, 2005; Fiedler et al., 2002). Based on the average of these tests, an bottom ash concentration of 46 ng I-TEQ/kg is assumed for all reference years. It is completely unknown how representative this facility is of U.S. facilities. Accordingly, it must be regarded as preliminary.

The total bottom ash generated was estimated by multiplying the mass of animals cremated per year (see above) and 5.5% ash content (value for humans from Forbes et al., 1953). This yields the following estimates:

- 1987—3.7 million kg
- 1995—4.1 million kg
- 2000—4.5 million kg

These estimates are considered preliminary because they are derived from Class D-rated estimates for mass of animals cremated.

The amounts of dioxin in landfilled ash were estimated by multiplying the bottom ash concentration by the ash activity level:

- 1987—0.17 g I-TEQ_{DF} (Preliminary)
- 1995—0.19 g I-TEQ_{DF} (Preliminary)
- 2000—0.21 g I-TEQ_{DF} (Preliminary)

The ash from these facilities is assumed to be landfilled and, therefore, is not considered a release to the open environment.

3.4.2.4. *Products—None*

3.4.2.5. *Release Summary*

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Animal Crematoria				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Animal Crematoria
Air Releases
Emission Factors • 1987—50 ng I-TEQ_{DF}/kg of animal cremated (Preliminary). • 1995—50 ng I-TEQ_{DF}/kg of animal cremated (Preliminary). • 2000—50 ng I-TEQ_{DF}/kg of animal cremated (Preliminary).
Activity Levels • 1987—68 million kg/yr. • 1995—74 million kg/yr. • 2000—81.9 million kg/yr.
Releases • 1987—3 g I-TEQ_{DF} (Preliminary). • 1995—4 g I-TEQ_{DF} (Preliminary). • 2000—4 g I-TEQ_{DF} (Preliminary).
Water Releases
None.
Solid Residue Releases
This ash is landfilled and, therefore, is not considered an environmental release.
Products
None.

3.5. SEWAGE SLUDGE INCINERATION

3.5.1. Air Releases

No changes were made to the air-release estimates. The emission factor of 6.7 ng WHO_{98} TEQ_{DF}/kg was derived from testing at 14 U.S. facilities and applied to all three reference years. UNEP (2005) recommends emission factors of 0.4 ng I-TEQ/kg for state-of-art facilities and 4 ng I-TEQ/kg for updated facilities with controls. The emission factor used here is similar to the UNEP recommendation for updated facilities with controls. The activity estimates were derived from survey data summarized in EPA, 2006.

3.5.2. Water Releases

Because some sewage sludge incinerators use wet scrubber systems, it is possible that water discharges occur. However, wastewater from wet scrubbers is often treated and then reintroduced to the wastewater treatment plant, so that no water discharges occur directly from the incinerator (in these cases, the CDD/CDFs in the effluent would likely end up in the sewage sludge). As discussed below, some limited information is available on dioxin levels in scrubber water. No information is available on quantities of scrubber effluent from U.S. facilities or what portion is recycled back to the wastewater treatment operation. Therefore, releases are possible, but no quantitative estimates could be made (Not quantifiable).

In Table 5-16 of EPA (1987), data are presented indicating that 2,3,7,8-TCDD was not detected in scrubber water filtrate from three sewage sludge incinerators. However, total CDDs for the three incinerators averaged 0.3 ng/kg, and total CDFs averaged 4 ng/kg. No data were given for any congeners (other than 2,3,7,8-TCDD), nor were there any data on the quantities of filtrate.

The European inventory (EU, 1999) reports concentrations between 1.2 and 6.5 pg I-TEQ/L in scrubber effluents from sewage sludge incinerators.

3.5.3. Solid Residue Releases

All ash from these facilities is assumed to be disposed in permitted landfills. As defined in this inventory, landfilled material does not represent a true release to the open environment and is not included in the source inventory. However, for informational purposes, the discussion below presents estimates of the amount of dioxin in landfilled ash.

Testing of multiple hearth furnaces in the United Kingdom (Dyke et al., 1997) showed CDD/CDF in the grate ash at concentrations of 39 ng TEQ/kg and 470 ng TEQ/kg in fly ash from the ESP. Rates of ash production were 430 kg/ton of grate ash and 13 kg/ton of ESP ash for the multiple hearth plant. Levels in ash (all the ash was collected in the ESP) from fluidized bed combustion were much lower (<1 ng TEQ/kg); 373 kg of ESP ash were produced per ton of sludge combusted in the fluidized bed.

In Table 5-16 of EPA (1987), data are presented indicating that 2,3,7,8-TCDD was not detected in the bottom ash from three sewage sludge incinerators. However, total CDDs for the three incinerators were nondetects, 20 ng/kg, and 10 ng/kg. For total CDFs, the values were nondetects, 70 ng/kg, and 50 ng/kg. No data were given for any congeners (other than 2,3,7,8-TCDD), nor were there any data on the quantities of ash.

UNEP (2005) recommends default residue emission factors of 0.5 ng I-TEQ/kg of sewage sludge for updated and modern furnaces. This was adopted for all reference years. This is considered a preliminary (Class D) estimate because there were no U.S. data and very limited European data to support it.

No data on ash generation rates were found. Rather, the activity was based on the annual amount of sewage sludge incinerated—see the discussion above.

The amounts of dioxin in landfilled ash were estimated by multiplying the emission factor by the activity level:

- 1987—0.43 g I-TEQ_{DF} (Preliminary)
- 1995—1.0 g I-TEQ_{DF} (Preliminary)
- 2000—0.71 g I-TEQ_{DF} (Preliminary)

The ash from these facilities is assumed to be landfilled and, therefore, is not considered a release to the open environment.

3.5.4. Products—None

3.5.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Sewage Sludge Incinerators				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Sewage Sludge Incinerators
Air Releases
Emission Factors • 1987—6.7 ng WHO_{98} TEQ_{DF}/kg (6.6 ng I-TEQ_{DF}/kg). • 1995—6.7 ng WHO_{98} TEQ_{DF}/kg (6.6 ng I-TEQ_{DF}/kg). • 2000—6.7 ng WHO_{98} TEQ_{DF}/kg (6.6 ng I-TEQ_{DF}/kg).
Activity Levels • 1987—0.865 billion kg of dry sewage sludge. • 1995—2.11 billion kg of dry sewage sludge. • 2000—1.42 billion kg of dry sewage sludge.
Releases • 1987—6 g WHO_{98} TEQ_{DF} (6 g I-TEQ_{DF}). • 1995—14 g WHO_{98} TEQ_{DF} (14 g I-TEQ_{DF}). • 2000—10 g WHO_{98} TEQ_{DF} (9 g I-TEQ_{DF}).
Water Releases
Possible but quantitative releases could not be made (Not quantifiable).
Solid Residue Releases
The ash from these facilities is assumed to be landfilled and, therefore, is not considered a release to the open environment.
Products
None.

3.6. TIRE COMBUSTION

This section covers releases from dedicated tire incinerators. Tires are also burned in cement kilns, which are covered in Section 5.1. Some are combusted as auxiliary fuel in industrial boilers and in pulp and paper mill combustion facilities, but the amount of tires going to these types of facilities is assumed to be negligible (note that emissions from industrial boilers are covered in Sections 3.2 and 4.3, and emissions from pulp and paper mills are covered in Sections 3.7 and 8.1). Additionally, tires may be unintentionally burned in an uncontrolled fashion at landfills (open burning). The open burning of tires is not discussed in this report due to the lack of information, and, thus, is an unquantifiable source.

3.6.1. Air Releases

No changes were made to the air-release estimates. The emission factor of 0.28 ng WHO_{98} TEQ_{DF}/kg was derived from testing at one facility that was equipped with a dry scrubber and fabric filter (CARB, 1991). Because other facilities may be equipped with less sophisticated air pollution control systems, the TEQ emissions could be higher. For example, Cains and Dyke (1994) reported much higher emission rates for two tire incinerators in the United Kingdom that were equipped with only simple grit arrestors. Because the emission factor is based on testing at only one facility and it is inconsistent with other data, the release estimate is considered preliminary. The activity estimates were derived from survey data from EPA, (1992b) and Rubber Manufacturers Association (RMA) (2002).

3.6.2. Water Releases

Some tire combustion facilities may have wet scrubbers indicating that water releases are possible. No information could be found on CDD/CDF levels in effluent or amounts of effluent discharged from these facilities. Therefore, releases are possible but could not be quantified (Not quantifiable).

3.6.3. Solid Residue Releases

Both bottom ash and fly ash can be created from tire combustion. No information could be found on CDD/CDF levels in ash or amounts of ash associated with these facilities. Any ash would be landfilled, and therefore, would not be considered an environmental release.

3.6.4. Products—None

3.6.5. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Tire Combustion				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Tire Combustion
Air Releases
Emission Factors • 1987—0.28 ng WHO_{98} TEQ_{DF}/kg (0.28 ng I-TEQ_{DF}/kg) (Preliminary). • 1995—0.28 ng WHO_{98} TEQ_{DF}/kg (0.28 ng I-TEQ_{DF}/kg) (Preliminary). • 2000—0.28 ng WHO_{98} TEQ_{DF}/kg (0.28 ng I-TEQ_{DF}/kg) (Preliminary).
Activity Levels • 1987—0.385 billion kg. • 1995—0.385 billion kg. • 2000—1.8 billion kg.
Releases • 1987—0.1 g WHO_{98} TEQ_{DF}/yr (0.1 g I-TEQ_{DF}/yr) (Preliminary). • 1995—0.1 g WHO_{98} TEQ_{DF}/yr (0.1 g I-TEQ_{DF}/yr) (Preliminary). • 2000—0.5 g WHO_{98} TEQ_{DF}/yr (0.5 g I-TEQ_{DF}/yr) (Preliminary).
Water Releases
Possible but quantitative releases could not be made (Not quantifiable).
Solid Residue Releases
Ash generated at these facilities is landfilled and, therefore, not considered an environmental release.
Products
None.

3.7. COMBUSTION OF WASTEWATER SLUDGE AT BLEACHED CHEMICAL PULP MILLS

Approximately 20.5% of the wastewater sludges generated at bleached chemical pulp mills are dewatered and burned in bark boilers at the mills (NCASI, 1995). These sludges can contain CDDs/CDFs and elevated levels of chloride (NCASI, 1995). However, the sludges generally make up less than 10% of the total feed to the boilers. Most of the feed is composed of wood residues. On this basis, it is believed that the dioxin emission estimates derived in Section 4.2.2 for industrial wood-burning facilities include emissions from boilers burning wastewater sludges generated at bleached chemical pulp mills.

3.8. BIOGAS COMBUSTION

No changes were made to the release estimates. The emission factor was derived from testing at one facility in Germany and was considered preliminary. The activity was derived from data on the amount of sewage sludge generated and assumptions about how much gas is generated from the sludge. No other water, solid residue, or product releases occur from this source. The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Biogas Combustion				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Biogas Combustion
Air Releases
Emission Factors • 1987—0.46 ng I-TEQ_{DF}/Nm^3 of digester gas combusted (Preliminary). • 1995—0.46 ng I-TEQ_{DF}/Nm^3 of digester gas combusted (Preliminary). • 2000—0.46 ng I-TEQ_{DF}/Nm^3 of digester gas combusted (Preliminary).
Activity Levels • 1987—467-million Nm^3 (Preliminary). • 1995—467-million Nm^3 (Preliminary). • 2000—467-million Nm^3 (Preliminary).
Releases • 1987—0.2 g I-TEQ_{DF}/yr (Preliminary). • 1995—0.2 g I-TEQ_{DF}/yr (Preliminary). • 2000—0.2 g I-TEQ_{DF}/yr (Preliminary).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	Annual air emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
MBWW H-ESP	1	Pinellas Co.	Pinellas Co.	FL	5.63E+08	478	535	269	301
	2	St. Petersburg	St. Petersburg	FL	3.24E+08	478	535	155	173
	3	Tampa	Tampa	FL	2.82E+08	478	535	135	151
	4	Chicago	Chicago	IL	4.51E+08	478	535	216	241
	5	North Andover	North Andover	MA	4.22E+08	Actual tested stack emissions		200	224
	6	Saugus	Saugus	MA	4.22E+08	478	535	202	226
	7	Baltimore (RESCO)	Baltimore	MD	6.34E+08	478	535	303	339
	8	Wilmington	Wilmington	NC	5.63E+07	478	535	27	30
	9	Glen Cove	Glen Cove	NY	7.04E+07	478	535	34	38
	10	Westchester Co.	Peekskill	NY	6.34E+08	Actual tested stack emissions		44	47
	11	Tulsa	Tulsa	OK	2.11E+08	478	535	101	113
	12	Harrisburg	Harrisburg	PA	2.03E+08	Actual tested stack emissions		147	167
	13	Philadelphia E.	Philadelphia	PA	2.11E+08	Actual tested stack emissions		100	112
	14	Philadelphia NW	Philadelphia	PA	2.11E+08	478	535	101	113
	15	Nashville Thermal	Nashville	TN	3.16E+08	478	535	151	169
	16	Hampton WTE	Hampton	VA	5.63E+07	Actual tested stack emissions		27	30
	17	Harrisonburg	Harrisonburg	VA	2.82E+07	478	535	13	15
	18	Norfolk	Norfolk NAS	VA	1.01E+08	Actual tested stack emissions		222	251
H-ESP subtotals					**5.20E+09**			**2,450**	**2,740**

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MBWW DS/FF	19	Marion Co.	Brooks	OR	1.55E+08	0.67	0.72	0.1	0.1
DS/FF subtotals					**1.55E+08**			**0.1**	**0.1**
Totals For Mass Burn Waterwall					**5.35E+09**			**2,450**	**2,740**
MB/REF H-ESP	20	Stamford I	Stamford	CT	5.63E+07	473	554	27	31
	21	Stamford II	Stamford	CT	1.01E+08	473	554	48	56
	22	Washington	Washington	DC	2.82E+08	473	554	133	156
	23	Baltimore (Pulaski)	Baltimore	MD	3.38E+08	Actual tested stack emissions		160	179
	24	Clinton	Clinton Township	MI	1.69E+08	473	554	80	94
	25	Brooklyn (Henry St.)	Brooklyn	NY	2.82E+08	473	554	133	156
	26	Brooklyn (SW)	Brooklyn	NY	2.11E+08	473	554	100	117
	27	Betts Avenue	Queens	NY	2.82E+08	473	554	133	156
	28	Euclid	Euclid	OH	5.63E+07	473	554	27	31
	29	Ogden	Layton	UT	1.27E+08	473	554	60	70
	30	Portsmouth	Portsmouth	VA	4.51E+07	473	554	21	25
	31	Waukesha	Waukesha	WI	4.93E+07	473	554	23	27
H-ESP subtotals					**2.00E+09**			**945**	**1,100**
MB/REF WS	32	New Canaan	New Canaan	CT	3.04E+07	236	254	7	8
	33	Louisville	Louisville	KY	2.82E+08	236	254	66	72
	34	Shreveport	Shreveport	LA	5.63E+07	236	254	13	14

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	Annual air emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
MB/REF WS (continued)	35	Fall River	Fall River	MA	1.69E+08	236	254	40	43
	36	S.E. Oakland Co.	Auburn Hills	MI	1.69E+08	236	254	40	43
	37	Huntington	Huntington	NY	1.27E+08	236	254	30	32
	38	Sheboygan	Sheboygan	WI	6.76E+07	236	254	16	17
WS subtotals					**9.01E+08**			**212**	**229**
MB/REF DS/FF	39	Framingham	Framingham	MA	1.41E+08	0.67	0.72	0.1	0.1
DS/FF subtotals					**1.41E+08**			**0.1**	**0.1**
Totals For Mass Burn Refractory					**3.04E+09**			**1,160**	**1,330**
MOD/SA H-ESP	40	Sitka	Sitka	AK	7.04E+06	79	85.7	0.6	0.6
	41	Tuscaloosa	Tuscaloosa	AL	8.45E+07	79	85.7	6.7	7.2
	42	Purham	Purham	MN	2.25E+07	79	85.7	1.8	1.9
	43	Red Wing	Red Wing	MN	2.03E+07	Actual tested stack emissions		0.1	0.1
	44	Savage	Savage	MN	1.69E+07	79	85.7	1.3	1.5
	45	Pascagoula	Moss Point	MS	4.22E+07	79	85.7	3.3	3.6
	46	Oswego Co.	Fulton	NY	5.63E+07	79	85.7	4.5	4.8
	47	Oneida Co.	Rome	NY	5.63E+07	Actual tested stack emissions		4.5	4.8
	48	Hampton	Hampton	SC	7.60E+07	79	85.7	6.0	6.5
	49	Cleburne	Clebume	TX	3.24E+07	79	85.7	2.6	2.8
	50	Barron Co.	Almena	WI	2.25E+07	79	85.7	1.8	1.9
H-ESP subtotals					**4.37E+08**			**33**	**36**

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								$I\text{-}TEQ_{DF}$	WHO_{98} TEQ_{DF}
MOD/SA UNC	51	Batesville	Batesville	AR	1.41E+07	16.2	17	0.2	0.2
	52	Blytheville	Blytheville	AR	1.97E+07	16.2	17	0.3	0.3
	53	Hope	Hope	AR	1.07E+07	16.2	17	0.2	0.2
	54	Hot Springs	Hot Springs	AR	2.82E+07	16.2	17	0.5	0.5
	55	North Little Rock	North Little Rock	AR	2.82E+07	16.2	17	0.5	0.5
	56	Osceola	Osceola	AR	1.41E+07	16.2	17	0.2	0.2
	57	Stuttgart	Stuttgart	AR	1.69E+07	16.2	17	0.3	0.3
	58	Cassia Co.	Burley	ID	1.41E+07	16.2	17	0.2	0.2
	59	Simpson Co.	Simpson Co.	KY	2.17E+07	16.2	17	0.3	0.4
	60	Harpswell	Harpswell	ME	3.94E+06	16.2	17	0.1	0.1
	61	Fort Leonard Wood	Fort Leonard Wood	MO	2.11E+07	16.2	17	0.3	0.4
	62	Livingston	Park Co.	MT	2.11E+07	16.2	17	0.3	0.4
	63	Wrightsville	Wrightsville	NC	1.41E+07	16.2	17	0.2	0.2
	64	Auburn	Auburn	NH	1.41E+06	16.2	17	<0.1	<0.1
	65	Candia	Candia	NH	4.22E+06	16.2	17	0.1	0.1
	66	Canterbury	Canterbury	NH	2.82E+06	16.2	17	0.1	0.1
	67	Durham	Durham	NH	3.04E+07	16.2	17	0.5	0.5
	68	Groveton	Groveton	NH	6.76E+06	16.2	17	0.1	0.1
	69	Litchfield	Litchfield	NH	6.20E+06	16.2	17	0.1	0.1
	70	Meredith	Meredith	NH	8.73E+06	16.2	17	0.1	0.2
MOD/SA	71	Nottingham	Nottingham	NH	2.25E+06	16.2	17	<0.1	<0.1

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	Annual air emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
UNC (continued)	72	Pittsfield	Pittsfield	NH	1.35E+07	16.2	17	0.2	0.2
	73	Wilton	Wilton	NH	8.45E+06	16.2	17	0.1	0.1
	74	Wolfeboro	Wolfeboro	NH	4.51E+06	16.2	17	0.1	0.1
	75	Cattaraugus Co.	Cuba	NY	3.15E+07	16.2	17	0.5	0.5
	76	Skaneateless	Skaneateless	NY	3.66E+06	16.2	17	0.1	0.1
	77	Miami	Miami	OK	3.04E+07	16.2	17	0.5	0.5
	78	Johnsonville	Johnsonville	SC	1.41E+07	16.2	17	0.2	0.2
	79	Dyersburg	Dyersburg	TN	2.82E+07	16.2	17	0.5	0.5
	80	Carthage City	Carthage City	TX	1.01E+07	16.2	17	0.2	0.2
	81	Center	Center	TX	1.01E+07	16.2	17	0.2	0.2
	82	Gatesville	Gatesville	TX	5.63E+06	16.2	17	0.1	0.1
	83	Newport News	Newport News	VA	9.86E+06	16.2	17	0.2	0.2
	84	Salem	Salem	VA	2.82E+07	16.2	17	0.5	0.5
	85	Bellingham	Bellingham	WA	2.82E+07	16.2	17	0.5	0.5
UNC subtotals					**5.17E+08**			**8.5**	**8.9**
MOD/SA WS	86	Collegeville	Collegeville	MN	1.41E+07	16.2	17	0.2	0.2
	87	Lewisburg	Lewisburg	TN	1.69E+07	16.2	17	0.3	0.3
	88	Palestine	Palestine	TX	7.89E+06	16.2	17	0.1	0.1
	89	Waxahachie	Waxahachie	TX	1.41E+07	16.2	17	0.2	0.2
WS subtotals					**5.30E+07**			**0.8**	**0.8**
MOD/SA	90	Windham	Windham	CT	3.04E+07	16.2	17	0.5	0.5

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
FF	91	Auburn	Auburn	ME	5.63E+07	16.2	17	0.9	1.0
	92	Portsmouth	Portsmouth	NH	5.63E+07	16.2	17	0.9	1.0
FF subtotals					**1.43E+08**			**2.3**	**2.5**
Totals For Modular-Starved Air					**1.15E+09**			**44**	**48**
MOD/EA UNC	93	Mayport	Mayport NAS	FL	1.35E+07	16.2	17	0.2	0.2
	94	Bellingham	Bellingham	WA	2.82E+07	16.2	17	0.5	0.5
UNC subtotals					**4.17E+07**			**0.7**	**0.7**
MOD/EA WS	95	East Chicago	East Chicago	IN	1.27E+08	16.2	17	2.1	2.2
WS subtotals					**1.27E+08**			**2.1**	**2.2**
MOD/EA EGB	96	Pittsfield	Pittsfield	MA	6.76E+07	0.67	0.72	0.1	0.1
EGB subtotals					**6.76E+07**			**0.1**	**0.1**
Totals For Modular Excess Air					**2.36E+08**			**2.8**	**2.9**
RDF/Co H-ESP	97	Lakeland	Lakeland	FL	8.45E+07	231	231	20	20
	98	Ames	Ames	IA	5.63E+07	231	231	13	13
H-ESP subtotals					**1.41E+08**			**33**	**33**
Totals For Refuse Derived Fuel Cofired With Coal					**1.41E+08**			**33**	**33**
RDF/Ded H-ESP	99	Dade Co.	Miami	FL	8.45E+08	1,490	1,680	1,260	1,420
	100	Honolulu	Honolulu	HI	1.69E+08	1,490	1,680	252	284
	101	Haverhill	Lawrence	MA	3.66E+08	Actual tested stack emissions		546	615
	102	Albany	Albany	NY	1.69E+08	1,490	1,680	252	284
	103	Niagara Falls	Niagara	NY	6.20E+08	1,490	1,680	924	1,040
	104	Akron	Akron	OH	2.82E+08	1,490	1,680	420	473

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	Annual air emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
	105	Columbus	Columbus	OH	5.63E+08	Actual tested stack emissions		840	946
H-ESP subtotals					**3.01E+09**			**4,490**	**5,060**
RDF/Ded WS	106	Duluth	Duluth	MN	1.13E+08	236	254	27	29
	107	St. Louis	St. Louis	MO	2.25E+08	236	254	53	53
WS subtotals					**3.38E+08**			**80**	**82**
Totals for refuse-derived fuel—dedicated					**3.49E+09**			**4570**	**5140**
MB/RK H-ESP	108	N. Dayton	Dayton	OH	1.69E+08	478	535	81	90
	109	S. Dayton	Dayton	OH	1.69E+08	478	535	81	90
	110	Gallatin	Gallatin	TN	5.63E+07	478	535	27	30
H-ESP subtotals					**3.94E+08**			**189**	**210**
MB/RK FF	111	Galax	Galax	VA	1.58E+07	47	93.1	0.7	1.5
FF subtotals					**1.58E+07**			**0.7**	**1.5**
Totals for mass burn rotary kiln					**4.10E+08**			**190**	**212**
TOTALS FOR ALL MWCs operating in 1987					**1.37E+10**			**8450**	**9510**

Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)

[a]MWC Design class: FB/RDF = Fluidized-bed refuse-derived fuel; MB/WW = Mass burn waterwall; MB/RK = Mass burn rotary kiln; MB/REF = Mass burn refractory walled; MOD/EA = Modular excess air; RDF/Ded = Dedicated refuse-derived fuel; RDF/co = Refuse-derived fuel cofired with coal (slash indicates devices used in conjunction).
[b]APCD = air pollution control device. This includes DS/FF (dry scrubber with fabric filters); H-ESP (hot-sided electrostatic precipitator); EGB (electrified gravel bed); WS (wet scrubber); FF (fabric filter); UNC = uncontrolled or no APCD.
[c]Activity Level is the annual amount (kg) of municipal solid waste or refuse derived fuel expected to be combusted by the MWC. It is estimated by multiplying the annual design capacity of the furnace by 85%. The figure of 85% represents the assumption that the MWC will experience downtime during the year for maintenance and repairs.
[d]The I-TEQ_{DF} Emission Factor (EF) expressed in units of ng TEQ/kg combusted.
[e]The WHO_{98} TEQ_{DF} Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MB/WW DS/FF	1	Huntsville RRF	Huntsville	AL	1.94E+08	0.67	0.72	0.1	0.1
	2	Long Beach RRF	Long Beach	CA	3.89E+08	0.67	0.72	0.3	0.3
	3	Commerce RRF	Commerce	CA	1.07E+08	Actual tested stack emissions		0.1	0.1
	4	Modesto RRF	Crows Landing	CA	2.25E+08	Actual tested stack emissions		0.1	0.2
	5	Bridgeport RESCO	Bridgeport	CT	6.34E+08	0.67	0.72	0.4	0.5
	6	Convanta SECONN	Preston	CT	1.69E+08	0.67	0.72	0.1	0.1
	7	Bristol RRF	Bristol	CT	1.83E+08	0.67	0.72	0.1	0.1
	8	Mid-Conn RRF	Hartford	CT	5.63E+08	0.67	0.72	0.4	0.4
	9	Pasco Co.	Hudson	FL	2.96E+08	0.67	0.72	0.2	0.2
	10	Broward Co. S	Fort Lauderdale	FL	6.34E+08	0.67	0.72	0.4	0.5
	11	Broward Co. N	Fort Lauderdale	FL	6.34E+08	0.67	0.72	0.4	0.5
	12	Lake Co. RRF	Okahumpka	FL	1.49E+08	0.67	0.72	0.1	0.1
	13	Savannah RRF	Savannah	GA	1.41E+08	0.67	0.72	0.1	0.1
	14	Indianapolis RRF	Indianapolis	IN	6.65E+08	Actual tested stack emissions		0.7	0.7
	15	Saugus RESCO	Saugus	MA	4.22E+08	Actual tested stack emissions		0.3	0.3
	16	Kent Co. RRF	Grand Rapids	MI	1.76E+08	0.67	0.72	0.1	0.1
	17	Jackson Co.	Jackson	MI	5.63E+07	0.67	0.72	<0.1	<0.1
	18	New Hanover	Wilmington	NC	7.01E+07	0.67	0.72	0.1	0.1
	19	Gloucester Co.	Westville	NJ	1.62E+08	0.67	0.72	0.1	0.1
	20	Warren Energy RRF	Oxford Township	NJ	1.13E+08	0.67	0.72	0.1	0.1

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MB/WW DS/FF (continued)	21	Onondaga Co.	Onondaga	NY	2.79E+08	0.67	0.72	0.2	0.2
	22	Babylon RRF	Babylon	NY	2.11E+08	Actual tested stack emissions		0.3	0.3
	23	Hempstead	Westbury	NY	7.06E+08	Actual tested stack emissions		0.1	0.1
	24	Marion Co.	Brooks	OR	1.55E+08	Actual tested stack emissions		<0.1	<0.1
	25	Montgomery Co.	Conshohocken	PA	3.38E+08	0.67	0.72	0.2	0.2
	26	Lancaster Co.	Bainbridge	PA	3.38E+08	0.67	0.72	0.2	0.2
	27	I-95 Energy RRF	Lorton	VA	8.45E+08	Actual tested stack emissions		0.9	1.0
	28	Spokane Regional	Spokane	WA	2.25E+08	0.67	0.72	0.2	0.2
	29	Skagit Co. RRF	Mount Vernon	WA	5.01E+07	0.67	0.72	<0.1	<0.1
DS/FF subtotals					**9.13E+09**			**6.3**	**6.8**
MB/WW C-ESP	30	Pinellas Co.	St. Petersburg	FL	8.45E+08	Actual tested stack emissions		5.2	5.5
	31	Hillsborough Co.	Tampa	FL	3.38E+08	6.1	6.54	2.1	2.2
	32	McKay Bay	Tampa	FL	2.82E+08	6.1	6.54	1.7	1.8
	33	Southernmost RRF	Key West	FL	4.22E+07	6.1	6.54	0.3	0.3
	34	Olmstead RRF	Rochester	MN	5.63E+07	6.1	6.54	0.3	0.4
	35	Westchester RESCO	Peekskill	NY	6.34E+08	6.1	6.54	3.9	4.1
	36	Walter B. Hall RRF	Tulsa	OK	3.17E+08	6.1	6.54	1.9	2.1
	37	Nashville Thermal	Nashville	TN	2.96E+08	6.1	6.54	1.8	1.9
C-ESP subtotals					**2.81E+09**			**17**	**18**

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MB/WW DS/C-ESP	38	Millbury	Millbury	MA	4.22E+08	6.1	6.54	2.6	2.8
	39	Greater Portland	Portland	ME	1.41E+08	Actual tested stack emissions		1.4	1.5
	40	Covanta Haverhill	Haverhill	MA	4.65E+08	6.1	6.54	2.8	3.0
	41	New Hanover	Wilmington	NC	5.63E+07	6.1	6.54	0.3	0.4
	42	Essex Co. RRF	Newark	NJ	6.41E+08	6.1	6.54	3.9	4.2
	43	Camden RRF	Camden	NJ	2.96E+08	Actual tested stack emissions		0.7	0.8
	44	Adirondack RRF	Hudson Falls	NY	1.22E+08	6.1	6.54	0.7	0.8
	45	Charleston RRF	Charleston	SC	1.69E+08	Actual tested stack emissions		1.0	1.1
DS/C-ESP subtotals					**2.73E+09**			**13**	**15**
MB/WW DSI/FF	46	SES Claremont RRF	Claremont	NH	5.63E+07	Actual tested stack emissions		0.2	0.2
	47	Concord	Concord	NH	1.41E+08	1.9	2.07	0.3	0.3
DSI/FF subtotals					**1.97E+08**			**0.5**	**0.5**
MB/WW DS/CI/FF	48	Hennepin Energy	Minneapolis	MN	3.38E+08	1.5	1.61	0.5	0.5
	49	Union Co. RRF	Rahway	NJ	4.06E+08	1.5	1.61	0.6	0.7
	50	Wheelabrator Falls	Falls Creek	PA	4.22E+08	Actual tested stack emissions		0.6	0.7
DS/CI/FF subtotals					**1.17E+09**			**1.7**	**1.9**
MB/WW H-ESP	51	University City RRF	Charlotte	NC	6.62E+07	478	535	32	35
	52	Long Beach RRF	Long Beach	NY	5.63E+07	478	535	27	30
	53	Harrisburg WTE	Harrisburg	PA	2.03E+08	Actual tested stack emissions		147	167
	54	NASA RRF	Hampton	VA	5.63E+07	Actual tested stack emissions		27	30

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ_{DF}	Annual air emissions (g/y) WHO_{98} TEQ_{DF}
MB/WW H-ESP (continued)	55	Harrisonburg RRF	Harrisonburg	VA	2.82E+07	Actual tested stack emissions		5.8	5.9
	56	Baltimore (RESCO)	Baltimore	MD	6.34E+08	Actual tested stack emissions		9.9	11
H-ESP subtotals					**1.04E+09**			**249**	**279**
MB/WW DSI/H-ESP	57	North Andover	North Andover	MA	4.22E+08	Actual tested stack emissions		3.3	3.5
DSI/H-ESP subtotals					**4.22E+08**			**3.3**	**3.5**
MB/WW DSI/CI/H-ESP	58	Alexandria RRF	Alexandria	VA	2.75E+08	Actual tested stack emissions		2.1	2.3
DSI/CI/H-ESP subtotals					**2.75E+08**			**2.1**	**2.3**
Totals for mass burn waterwall					**1.74E+10**			**293**	**327**
MB/REF WS	59	New Canaan MWC	New Canaan	CT	3.52E+07	236	254	8.3	9.0
	60	Fall River	Fall River	MA	1.69E+08	236	254	40	43
Subtotals for MB/REF WS					**2.04E+08**			**48**	**52**
MB/REF DS/C-ESP	61	Pulaski	Baltimore	MD	4.22E+08	Actual tested stack emissions		22	22
DS/C-ESP subtotals					**4.22E+08**			**22**	**22**
MB/REF C-ESP	62	Clinton	Clinton	MI	1.69E+08	Actual tested stack emissions		40	43
C-ESP subtotals					**1.69E+08**			**40**	**43**
MB/REF DS/FF	63	Mid Maine Waste	Auburn	ME	5.63E+07	0.67	0.72	<0.1	<0.1
	64	Huntington	Huntington	NY	2.11E+08	0.67	0.72	0.1	0.2
DS/FF subtotals					**2.67E+08**			**0.1**	**0.2**

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								$I\text{-}TEQ_{DF}$	WHO_{98} TEQ_{DF}
MB/REF DSI/FF	65	Davis Co.	Layton	UT	1.13E+08	1.91	2.07	0.2	0.2
DSI/FF subtotals					**1.13E+08**			**0.2**	**0.2**
Totals for mass burn refractory					**1.18E+09**			**110**	**117**
MB/RK C-ESP	66	Montenay Bay	Panama City	FL	1.44E+08	47	93.1	6.8	13
	67	Sumner Co.	Gallatin	TN	5.63E+07	47	93.1	2.7	5.2
MB/RK C-ESP subtotals					**2.00E+08**			**9.5**	**18**
MB/RK DSI/C-ESP	68	Dayton RRF	Dayton	OH	5.07E+08	47	93.1	24	47
DSI/C-ESP subtotals					**5.07E+08**			**24**	**47**
MB/RK DSI/FF	69	Dutchess Co.	Poughkeepsie	NY	1.13E+08	Actual tested stack emissions		5.3	10
	70	MacArthur WTE	Ronkonkoma	NY	1.46E+08	47	93.1	6.7	14
DSI/FF subtotals					**2.59E+08**			**12**	**24**
MB/RK DS/FF	71	Delaware Co.	Chester	PA	7.57E+08	0.62	0.68	0.5	0.5
	72	York Co.	York	PA	3.79E+08	Actual tested stack emissions		0.2	0.3
DS/FF subtotals					**1.14E+09**			**0.7**	**0.8**
Totals for mass burn rotary kiln					**2.10E+09**			**46**	**90**
RDF/ded C-ESP	73	Dade Co. RRF	Miami	FL	8.45E+08	231	253	199	214
	74	Niagara Falls RDF	Niagara Falls	NY	6.20E+08	Actual tested stack emissions		143	157
	75	Central Wayne Co.	Dearborn	MI	1.41E+08	Actual tested stack emissions		33	36
	76	Ramsey-WA	Red Wing	MN	2.03E+08	231	253	47	51

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
RDF/ded C-ESP subtotals					**1.81E+09**			**422**	**458**
RDF/ded DS/C-ESP	77	West Palm Beach	Palm Beach	FL	5.63E+08	0.53	0.56	0.3	0.3
	78	SEMASS RRF	Rochester	MA	5.07E+08	0.53	0.56	0.3	0.3
	79	Western L Superior	Duluth	MN	7.32E+07	0.53	0.56	<0.1	<0.1
	80	Honolulu RRF	Honolulu	HI	6.08E+08	0.53	0.56	0.3	0.3
DS/C-ESP subtotals					**1.75E+09**			**0.9**	**0.9**
RDF/ded DS/FF	81	SEMASS RRF	Rochester	MA	7.60E+08	0.24	0.26	0.2	0.2
	82	Maine Energy RRF	Biddeford	ME	1.69E+08	Actual tested stack emissions		0.1	0.1
	83	Penobscot Energy	Orrington	ME	1.97E+08	Actual tested stack emissions		<0.1	<0.1
	84	Greater Detroit RRF	Detroit	MI	6.20E+08	Actual tested stack emissions		0.1	0.2
	85	Wilmarth Plant	Mankato	MN	2.03E+08	47	93.1	0.1	0.1
	86	Norfolk Navy Yard	Norfolk	VA	5.63E+08	0.24	0.26	0.1	0.1
	87	Mid-Connecticut	Hartford	CT	5.63E+08	Actual tested stack emissions		0.1	0.1
DS/FF subtotals					**3.07E+09**			**0.7**	**0.8**
RDF/ded DSI/FF	88	Elk River RRF	Elk River	MN	4.22E+08	47	93.1	20	39
DSI/FF subtotals					**4.22E+08**			**20**	**39**
RDF/ded DSI/H-ESP	89	Haverhill Lawrence	Lawrence	MA	2.00E+08	285	316	57	63
DSI/H-ESP subtotals					2.00E+08			57	63
RDF/ded H-ESP	90	Kodak MWC	Rochester	NY	4.22E+07	1,490	1,680	63	71
H-ESP subtotals					**4.22E+07**			**63**	**71**

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								$I\text{-}TEQ_{DF}$	WHO_{98} TEQ_{DF}
Totals for dedicated refuse derived fuel					**7.30E+09**			**564**	**633**
MOD/SA UNC	91	Batesville MWC	Batesville	AR	2.82E+07	16.2	17	0.5	0.5
	92	Stuttgart MWC	Stuttgart	AR	1.77E+07	16.2	17	0.3	0.3
	93	Osceola MWC	Osceola	AR	1.41E+07	16.2	17	0.2	0.2
	94	Miami Airport	Miami	FL	1.69E+07	16.2	17	0.3	0.3
	95	NIEHS MWC	Durham	NC	1.13E+07	16.2	17	0.2	0.2
	96	Livingston/Park Co.	Park Co.	MT	2.03E+07	16.2	17	0.3	0.3
	97	Miami MWC	Miami	OH	2.96E+07	16.2	17	0.5	0.5
	98	Coos Bay MWC	Coquille	OR	3.52E+07	16.2	17	0.6	0.6
	99	Pentagon MWC	Arlington	VA	1.41E+07	16.2	17	0.2	0.2
UNC subtotals					**1.87E+08**			**3.1**	**3.1**
MOD/SA H-ESP	100	Juneau MWC	Juneau	AK	1.97E+07	79	85.7	1.6	1.7
	101	Harford Co.	Aberdeen	MD	1.01E+08	79	85.7	8.0	8.7
	102	City of Clebume	Clebume	TX	3.24E+07	79	85.7	2.6	2.8
	103	Barron Co.	Almena	WI	2.82E+07	79	85.7	2.2	2.4
H-ESP subtotals					**1.81E+08**			**14**	**16**
MOD/SA C-ESP	104	Perham MWC	Perham	MN	3.21E+07	16.2	17	0.5	0.6
	105	Polk Co. MWC	Fosston	MN	2.25E+07	16.2	17	0.4	0.4
	106	Oswego Co.	Fulton	NY	5.63E+07	16.2	17	0.9	1.0
	107	Westmoreland	Greensburg	PA	1.41E+07	16.2	17	0.2	0.2
C-ESP subtotals					**1.25E+08**			**2.0**	**2.2**

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y)	
								$I\text{-}TEQ_{DF}$	WHO_{98} TEQ_{DF}
MOD/SA DS/DSI/C-ESP	108	Chamber Medical	Hampton	SC	7.60E+07	16.2	17	1.2	1.3
DS/DSI/C-ESP subtotals					**7.60E+07**			**1.2**	**1.3**
MOD/SA DSI/FF	109	St. Croix WTE	New Richmond	WI	2.87E+07	0.02	0.03	<0.1	<0.1
DSI/FF subtotals					**2.87E+07**			**<0.1**	**<0.1**
MOD/SA WS	110	Fergus Falls	Fergus Falls	MN	2.65E+07	16.2	17	0.4	0.5
	111	Center MWC	Center	TX	1.13E+07	16.2	17	0.2	0.2
	112	Panola Co.	Carthage	TX	1.13E+07	16.2	17	0.2	0.2
WS subtotals					**4.90E+07**			**0.8**	**0.9**
MOD/SA WS/FF	113	Recomp Bellingham	Bellingham	WA	2.82E+07	16.2	17	0.5	0.5
WS/FF subtotals					**2.82E+07**			**0.5**	**0.5**
Totals for modular-starved air					**6.46E+08**			**22**	**24**
MOD/EA UNC	114	Mayport NAS	Mayport	FL	1.41E+07	16.2	17	0.2	0.2
UNC subtotals					**1.41E+07**			**0.2**	**0.2**
MOD/EA H-ESP	115	Richards Asphalt Co.	Savage	MN	1.97E+07	Actual tested stack emissions		2.3	2.4
H-ESP subtotals					**1.97E+07**			**2.3**	**2.4**
MOD/EA DSI/H-ESP	116	Sitka MWC	Sitka	AK	1.41E+07	118	119	1.7	1.7
DSI/H-ESP subtotals					**1.41E+07**			**1.7**	**1.7**
MOD/EA C-ESP	117	Pope-Douglas SW	Alexandria	MN	2.03E+07	Actual tested stack emissions		0.3	0.3
	118	Red Wing	Red Wing	MN	2.03E+07	Actual tested stack emissions		0.1	0.1

Table 3-2. Inventory of municipal waste combustors (MWCs) in 1995 (continued)

Design[a] class APCD[b]		Facility name	City located	State	Activity level[c] (kg/y)	I-TEQ EF[d] (ng/kg)	WHO TEQ EF[e] (ng/kg)	Annual air emissions (g/y) I-TEQ$_{DF}$	Annual air emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
	119	Pascagoula RRF	Moss Point	MS	4.22E+07	16.2	17	0.7	0.7
C-ESP subtotals					**8.28E+07**			**1.1**	**1.1**
MOD/EA DS/FF	120	Wallingford RRF	Wallingford	CT	1.18E+08	16.2	17	1.9	2.0
DS/FF subtotals					**1.18E+08**			**1.9**	**2.0**
MOD/EA DSI/FF	121	Springfield RRF	Agawam	MA	1.01E+08	16.2	17	1.6	1.7
DSI/FF subtotals					**1.01E+08**			**1.6**	**1.7**
MOD/EA WS/C-ESP	122	Pittsfield RRF	Pittsfield	MA	6.76E+07	Actual tested stack emissions		1.1	1.2
WS/C-ESP subtotals					**6.76E+07**			**1.1**	**1.2**
Totals for modular excess air					**4.17E+08**			**10**	**10**
FB/RDF DS/FF	123	Fayetteville RRF	Fayetteville	NC	1.69E+08	0.67	0.72	0.1	0.1
DS/FF subtotals					**1.69E+08**			**0.1**	**0.1**
FB/RDF DSI/FF	124	Tacoma RRF	Tacoma	WA	8.45E+07	0.67	0.72	0.1	0.1
DSI/FF subtotals					**8.45E+07**			**0.1**	**0.1**
FB/RDF DSI/EGB	125	LaCrosse Co.	La Crosse	WI	1.13E+08	Actual tested stack emissions		0.1	0.1
DSI/EGB subtotals					**1.13E+08**			**0.1**	**0.1**
Totals for fluidized bed/refuse-derived fuel					**3.66E+08**			**0.3**	**0.3**
Totals for all MWCs operating in 1995					**2.98E+10**			**1050**	**1200**

[a]MWC Design class: FB/RDF = Fluidized-bed refuse-derived fuel; MB/WW = Mass burn waterwall; MB/RK = Mass burn rotary kiln; MB/REF = Mass burn refractory walled; MOD/EA = Modular excess air; RDF/Ded = Dedicated refuse-derived fuel; RDF/co = Refuse-derived fuel cofired with coal (slash indicates devices used in conjunction).

[b]APCD = air pollution control device. This includes DS/FF (dry scrubber with fabric filters); H-ESP (hot-sided electrostatic precipitator); EGB (electrified gravel bed); WS (wet scrubber); FF (fabric filter); UNC = uncontrolled or no APCD.
[c]Activity Level is the annual amount (kg) of municipal solid waste or refuse derived fuel expected to be combusted by the MWC. It is estimated by multiplying the annual design capacity of the furnace by 85%. The figure of 85% represents the assumption that the MWC will experience downtime during the year for maintenance and repairs.
[d]The I-TEQ_{DF} Emission Factor (EF) expressed in units of ng TEQ/kg combusted.
[e]The WHO_{98} TEQ_{DF} Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$	I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MB/WW DS/FF/CI/SNCR	1	Huntsville	Madison	AL	1.77E+08	Tested	Tested	<0.1	<0.1
	2	Stanislaus	Stanislaus	CA	2.61E+08	Tested	Tested	<0.1	<0.1
	3	Bristol RRF	Hartford	CT	1.86E+08	Tested	Tested	<0.1	<0.1
	4	Wheelabrator Lisbon Inc.	New London	CT	1.79E+08	Tested	Tested	<0.1	<0.1
	5	Hillsborough Co. RRF	Hillsborough	FL	3.58E+08	Tested	Tested	0.1	0.1
	6	McKay Bay REF	Hillsborough	FL	1.80E+08	Tested	Tested	<0.1	<0.1
	7	Lake Co. RRF	Lake	FL	1.66E+08	Tested	Tested	0.1	0.1
	8	Lee Co. RRF	Lee	FL	3.95E+08	Tested	Tested	0.2	0.2
	9	Pasco Co. RRF	Pasco	FL	3.10E+08	Tested	Tested	<0.1	<0.1
	10	Pinellas Co. RRF	Pinellas	FL	8.91E+08	Tested	Tested	0.1	0.2
	11	Savannah RRF	Chatham	GA	1.21E+08	Tested	Tested	<0.1	<0.1
	12	Indianapolis RRF	Marion	IN	6.54E+08	Tested	Tested	0.1	0.1
	13	Haverhill RRF	Essex	MA	5.68E+08	Tested	Tested	0.1	0.1
	14	Wheelabrator North Andover	Essex	MA	3.83E+08	Tested	Tested	<0.1	<0.1
	15	Wheelabrator Saugus	Essex	MA	4.32E+08	Tested	Tested	<0.1	<0.1
	16	Montgomery Co. RRF	Montgomery	MD	5.20E+08	Tested	Tested	0.3	0.3
	17	Kent Co. WTE Facility	Kent	MI	1.80E+08	Tested	Tested	0.02	0.02
	18	Central Wayne Energy	Wayne	MI	6.18E+07	Tested	Tested	<0.1	<0.1
	19	Covanta Hennepin	Hennepin	MN	3.65E+08	Tested	Tested	0.1	0.1
	20	New Hanover Co. WTE	New Hanover	NC	1.27E+08	Tested	Tested	<0.1	<0.1
	21	Wheelabrator Concord	Merrimack	NH	1.84E+08	Tested	Tested	<0.1	<0.1

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000 (continued)

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg) I-TEQ_{DF}	Emission Factor (ng TEQ/kg) WHO_{98} TEQ_{DF}	Annual Air Emissions (g/y) I-TEQ_{DF}	Annual Air Emissions (g/y) WHO_{98} TEQ_{DF}
MB/WW DS/FF/CI/SNCR (continued)	22	Gloucester Co.	Gloucester	NJ	1.81E+08	Tested	Tested	<0.1	<0.1
	23	Union Co. RRF	Union	NJ	5.09E+08	Tested	Tested	<0.1	<0.1
	24	Niagara Falls	Niagara	NY	7.14E+08	Tested	Tested	0.4	0.4
	25	Onondaga Co. RRF	Onondaga	NY	3.35E+08	Tested	Tested	<0.1	<0.1
	26	Babylon RRF	Suffolk	NY	2.20E+08	Tested	Tested	<0.1	<0.1
	27	Huntington RRF	Suffolk	NY	3.16E+08	Tested	Tested	<0.1	<0.1
	28	Wheelabrator Westchester	Westchester	NY	6.50E+08	Tested	Tested	0.1	0.1
	29	Walter B. Hall RRF (Tulsa)	Tulsa	OK	3.39E+08	Tested	Tested	<0.1	<0.1
	30	Marion Co. WTE	Marion	OR	1.84E+08	Tested	Tested	<0.1	<0.1
	31	Lancaster Co.	Bainbridge	PA	3.81E+08	Tested	Tested	0.1	0.1
	32	Wheelabrator Falls RRF	Bucks	PA	5.25E+08	Tested	Tested	<0.1	<0.1
	33	Montenay Montgomery	Montgomery	PA	4.03E+08	Tested	Tested	0.5	0.6
	34	Nashville Thermal Transfer Corp.	Davidson	TN	2.25E+08	Tested	Tested	<0.1	<0.1
	35	Alexandria/Arlington RRF	Alexandria	VA	3.32E+08	Tested	Tested	0.1	0.1
	36	I-95 Energy RRF	Fairfax	VA	1.09E+09	Tested	Tested	<0.1	<0.1
	37	Spokane Regional Facility	Spokane	WA	2.85E+08	Tested	Tested	<0.1	<0.1
		DS/FF/CI/SNCR subtotals			**1.34E+10**			**2.3**	**2.5**
MB/WW DS/FF/SNCR	38	Long Beach SERRF	Los Angeles	CA	5.74E+08	Tested	Tested	0.1	0.1
	39	Wheelabrator South Broward	Ft. Lauderdale	FL	7.56E+08	Tested	Tested	0.2	0.2
	40	Wheelabrator North Broward	Broward	FL	7.76E+08	Tested	Tested	0.1	0.1
	41	Hempstead	Nassau	NY	8.87E+08	Tested	Tested	0.5	0.5
		DS/FF/SNCR subtotals			**2.99E+09**			**0.9**	**0.9**
MB/WW DS/FF/CI	42	Wheelabrator Bridgeport, L.P.	Fairfield	CT	7.08E+08	Tested	Tested	0.1	0.1
	43	Southeastern Connecticut RRF	New London	CT	7.08E+08	Tested	Tested	0.1	0.1
	44	Warren Energy RF	Warren	NJ	1.25E+08	Tested	Tested	<0.1	<0.1
		DS/FF/CI subtotals			**1.25E+08**			**0.2**	**0.2**
MB/WW DS/FF	45	Jackson Co. RRF	Jackson	MI	6.27E+07	0.67	0.72	<0.1	0.1
	46	New Hanover Co.	New Hanover	NC	6.27E+07	0.67	0.72	<0.1	0.1
	47	SES Claremont	Sullivan	NH	6.27E+07	0.67	0.72	<0.1	0.1
		DS/FF subtotals			**1.88E+08**			**<0.1**	**0.3**

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000 (continued)

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$	I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
MB/WW DS/ESP/CI/SNCR	48	McKay Bay REF	Hillsborough	FL	1.80E+08	Tested	Tested	<0.1	<0.1
	49	Wheelabrator Millbury	Worcester	MA	4.64E+08	Tested	Tested	0.1	0.1
	50	Wheelabrator Baltimore	Independent City	MD	7.15E+08	Tested	Tested	0.4	0.4
	51	Greater Portland Region RRF	Cumberland	ME	1.73E+08	Tested	Tested	0.2	0.2
	52	Camden RRF	Camden	NJ	2.77E+08	Tested	Tested	0.4	0.4
	53	Essex Co. RRF	Essex	NJ	9.85E+08	Tested	Tested	0.2	0.2
		DS/ESP/CI/SNCR subtotals			**2.79E+09**			**1.3**	**1.3**
MB/WW DS/ESP/CI	54	Adirondack RRF	Washington	NY	1.62E+08	Tested	Tested	1.0	1.0
	55	Foster Wheeler Charleston RRF	Charleston	SC	2.11E+08	Tested	Tested	0.3	0.3
		DS/ESP/CI subtotals			**3.74E+08**			**1.3**	**1.3**
MB/WW C-ESP	56	Southernmost WTE	Monroe	FL	3.74E+08	6.1	6.54	2.3	2.4
	57	Olmstead WTE Facility	Olmstead	MN	6.27E+07	6.1	6.54	0.4	0.4
	58	NASA	Hampton City	VA	6.27E+07	6.1	6.54	0.4	0.4
		C-ESP subtotals			**4.99E+08**			**3.1**	**3.2**
MB/WW H-ESP	59	Harrisburg WTE	Dauphin	PA	1.54E+08	Tested	Tested	21	23
		H-ESP subtotals			**1.54E+08**			**21**	**23**
MB/WW UNC	60	Harrisonburg	Harrisonburg	VA	3.14E+07	1.9	2.07	0.1	0.1
		UNC subtotals			**3.14E+07**			**0.1**	**0.1**
Totals for all MB/WW					**2.05E+10**			**30**	**33**
MB/REF DSI/H-ESP	61	Davis/Wasatch	Davis	UT	1.25E+08	Tested	Tested	2.7	2.9
		DSI/H-ESP subtotals			**1.25E+08**			**2.7**	**2.9**
MB/REF DS/FF	62	Mid Maine Waste Action Corp.	Androscoggin	ME	6.27E+07	0.67	0.72	<0.1	0.1
		DS/FF subtotals			**6.27E+07**			**<0.1**	**0.1**
Totals for all MB/REF					**1.88E+08**			**2.7**	**3.0**
MB/RK DS/FF	63	American Ref-Fuel of Delaware Valley	Delaware	PA	1.11E+09	Tested	Tested	0.5	0.5
		DS/FF subtotals			**1.11E+09**			**0.5**	**0.5**
MB/RK DS/FF/CI/SNCR	64	York Co.	York	PA	3.97E+08	Tested	Tested	0.1	0.1
		DS/FF/CI/SNCR subtotals			**3.97E+08**			**0.1**	**0.1**
MB/RK DSI/FF	65	Dutchess Co. RRF	Dutchess	NY	1.25E+08	Tested	Tested	<0.1	0.1
	66	MacArthur WTE	Suffolk	NY	1.52E+08	Tested	Tested	<0.1	<0.1

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000 (continued)

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$	I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
		DSI/FF subtotals			**2.78E+08**			**<0.1**	**0.1**
MB/RK	67	Galax City SW	Grayson	VA	1.76E+07	Tested	Tested	0.2	0.3
FF		**FF subtotals**			**1.76E+07**			**0.2**	**0.3**
MB/RK	68	Bay Resource Management Center	Bay	FL	1.54E+08	Tested	Tested	8.1	8.9
H-ESP		**H-ESP subtotals**			**1.54E+08**			**8.1**	**8.9**
MB/RK	69	Sumner Co.	Sumner	TN	6.27E+07	47	93.1	3.0	5.9
C-ESP		**C-ESP subtotals**			**6.27E+07**			**3.0**	**5.9**
Totals for all MB/RK					**2.02E+09**			**12**	**16**
MOD/EA	70	Wallingford RRF	New Haven	CT	1.32E+08	Tested	Tested	0.1	0.1
DS/FF		**DS/FF subtotals**			**1.32E+08**			**0.1**	**0.1**
MOD/EA	71	Springfield RRF	Hampden	MA	1.13E+08	0.025	0.024	<0.1	<0.1
DSI/FF		**DSI/FF subtotals**			**1.13E+08**			**<0.1**	**<0.1**
MOD/EA	72	Pittsfield RRF	Berkshire	MA	1.13E+08	16.2	17	1.8	1.9
WS/C-ESP		**WS/C-ESP subtotals**			**1.13E+08**			**1.8**	**1.9**
MOD/EA	73	Pope-Douglas Waste	Douglas	MN	2.26E+07	16.2	17	0.4	0.4
C-ESP	74	Red Wing Solid Waste Boiler Facility	Goodhue	MN	2.26E+07	16.2	17	0.4	0.4
		C-ESP subtotals			**4.52E+07**			**0.8**	**0.8**
MOD/EA	75	Pascagoula	Jackson	MS	4.70E+07	118	119	5.6	5.6
H-ESP		**H-ESP subtotals**			**4.70E+07**			**5.6**	**5.6**
Totals for all MOD/EA					**4.50E+08**			**8.3**	**8.4**
MOD/SA	76	Juneau RRF	Juneau Borough	AK	2.20E+07	16.2	17	0.4	0.4
C-ESP	77	Perham Renewable RF	Otter Tail	MN	3.57E+07	16.2	17	0.6	0.6
	78	Polk Co.	Polk	MN	2.51E+07	16.2	17	0.4	0.4
	79	Barron Co.	Barron	WI	3.14E+07	16.2	17	0.5	0.5
		C-ESP subtotals			**1.14E+08**			**1.9**	**1.9**
MOD/SA	80	City of Cleburne	Johnson	TX	3.57E+07	16.2	17	0.6	0.6
DSI/C-ESP		**DSI/C-ESP subtotals**			**3.57E+07**			**0.6**	**0.6**
MOD/SA	81	Harford Co. WTE Fac.	Harford	MD	1.13E+08	Tested	Tested	5.4	6.0
DSI/H-ESP		**DSI/H-ESP subtotals**			**1.13E+08**			**5.4**	**6.0**
MOD/SA	82	Oswego Co. WTE	Oswego	NY	6.27E+07	Tested	Tested	0.1	0.1
DS/FF/CI		**DS/FF/CI subtotals**			**6.27E+07**			**0.1**	**0.1**

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000 (continued)

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg) I-TEQ$_{DF}$	Emission Factor (ng TEQ/kg) WHO$_{98}$ TEQ$_{DF}$	Annual Air Emissions (g/y) I-TEQ$_{DF}$	Annual Air Emissions (g/y) WHO$_{98}$ TEQ$_{DF}$
MOD/SA	83	Coos Bay Incinerator	Coos	OR	4.70E+07	Tested	Tested	<0.1	<0.1
DSI/FF		**DSI/FF subtotals**			**4.70E+07**			**<0.1**	**<0.1**
MOD/SA	84	Arlington -Pentagon	Arlington	VA	3.14E+07	16.2	17	0.5	0.5
		MOD/SA subtotals			**3.14E+07**			**0.5**	**0.5**
MOD/SA WS	85	Fergus Falls	Otter Tail	MN	2.95E+07	16.2	17	0.5	0.5
	86	Panola Co. WTE	Panola	TX	1.25E+07	16.2	17	0.2	0.2
	87	Center RRF	Shelby	TX	1.25E+07	16.2	17	0.2	0.2
		WS subtotals			**5.46E+07**			**0.9**	**0.9**
MOD/SA UNC	88	Miami Airport	Dade	FL	1.88E+07	16.2	17	0.3	0.3
	89	Livingston/Park Co.	Park	MT	2.26E+07	16.2	17	0.4	0.4
	90	Miami RRF	Ottawa	OK	3.29E+07	16.2	17	0.5	0.6
		UNC subtotals			**7.43E+07**			**1.2**	**1.3**
Totals for all MOD/SA					**5.33E+08**			**10**	**11**
RDF/Ded DS/FF/SNCR	91	Mid-Connecticut RRF	Hartford	CT	7.50E+08	Tested	Tested	0.1	0.1
	92	SEMASS RRF	Plymouth	MA	3.65E+08	Tested	Tested	<0.1	<0.1
	93	Maine Energy Recovery	York	ME	2.47E+08	Tested	Tested	<0.1	<0.1
	94	Wilmarth Plant	Blue Earth	MN	2.03E+08	Tested	Tested	0.1	0.1
		DS/FF/SNCR subtotals			**1.57E+09**			**0.2**	**0.2**
RDF/Ded DS/FF/CI/SNCR	95	Dade Co. RRF	Dade	FL	6.68E+08	Tested	Tested	1.3	1.4
		DS/FF/CI/SNCR subtotals			**6.68E+08**			**1.3**	**1.4**
RDF/Ded DS/FF	96	Penobscot Energy Recovery	Penobscot	ME	2.20E+08	Tested	Tested	<0.1	<0.1
	97	Greater Detroit RRF	Wayne	MI	6.93E+08	Tested	Tested	0.5	0.5
	98	Great River Energy	Sherburne	MN	2.85E+08	Tested	Tested	0.1	0.1
	99	SPSA Waste to Energy	Portsmouth	VA	4.89E+08	Tested	Tested	0.5	0.5
		DS/FF subtotals			**1.69E+09**			**1.1**	**1.1**
RDF/Ded DSI/FF	100	Red Wing Plant	Goodhue	MN	1.82E+08	Tested	Tested	0.1	0.1
		DSI/FF subtotals			**1.82E+08**			**0.1**	**0.1**
RDF/Ded	101	LaCrosse Co.	LaCrosse	WI	4.44E+07	Tested	Tested	0.7	0.7

Table 3-3. Inventory of municipal waste combustors (MWCs) in 2000 (continued)

Design[a] Class APCD[b]		Facility Name	City Located	State	Activity Level[c] (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$	I-TEQ$_{DF}$	WHO$_{98}$ TEQ$_{DF}$
DSI/FF/WSp/SNCR		**DSI/FF/WSp/SNCR subtotals**			**4.44E+07**			**0.7**	**0.7**
RDF/Ded	102	Central Wayne Co.	Wayne	MI	1.56E+08	Tested	Tested	0.1	0.1
C-ESP		**C-ESP subtotals**			**1.56E+08**			**0.1**	**0.1**
RDF/Ded	103	Honolulu RRF	Honolulu	HI	5.15E+08	Tested	Tested	2.0	2.2
DS/ESP		**DS/ESP subtotals**			**5.15E+08**			**2.0**	**2.2**
RDF/Ded	104	SEMASS RRF	Plymouth	MA	7.41E+08	Tested	Tested	0.1	0.10
DS/ESP/FF/CI		**DS/ESP/FF/CI subtotals**			**7.41E+08**			**0.1**	**0.10**
Totals for all RDF/Ded					**5.56E+09**			**5.6**	**5.9**
FB/RDF	105	Tacoma	Pierce	WA	9.41E+07	0.67	0.72	0.1	0.1
DSI/FF		**DSI/FF subtotals**			**9.41E+07**			**0.1**	**0.1**
Totals for all FB/RDF					**9.41E+07**			**0.1**	**0.1**
Totals for all MWCs operating in year 2000					**2.94E+10**			**69**	**77**

[a]MWC Design class: FB/RDF = Fluidized-bed refuse-derived fuel; MB/WW = Mass burn waterwall; MB/RK = Mass burn rotary kiln; MB/REF = Mass burn refractory walled; MOD/EA = Modular excess air; RDF/Ded = Dedicated refuse-derived fuel.
[b]APCD = air pollution control device. DS/FF/CI/SNCR (dry scrubber followed by fabric filter with carbon injection and nitrogen oxide control); DS/FF/SNCR (dry scrubber followed by fabric filter with nitrogen oxide control); DS/FF/CI (dry scrubber followed by fabric filter with carbon injection); DS/FF (dry scrubber followed by fabric filter); DSI/FF (duct sorbent injection followed by fabric filter); DSI/FF/WSp/SNCR (duct sorbent injection followed by fabric filter with water spray and nitrogen oxide control); DS/ESP/CI/SNCR (dry scrubber followed by electrostatic precipitator with carbon injection and nitrogen oxide control); DS/ESP/CI (dry scrubber followed by electrostatic precipitator with carbon injection); C-ESP (cold-sided electrostatic precipitator); H-ESP (hot-sided electrostatic precipitator); DSI/C-ESP (duct sorbent injection followed by cold-sided electrostatic precipitator); DSI/H-ESP (duct sorbent injection followed by hot-sided electrostatic precipitator); WS (wet scrubber); WS/C-ESP (wet scrubber followed by cold-sided electrostatic precipitator); UNC (uncontrolled).
[c]Activity Level is the annual amount (kg) of municipal solid waste or refuse derived fuel expected to be combusted by the MWC. It is estimated by multiplying the annual design capacity of the furnace by 85%. The figure of 85% represents the assumption that the MWC will experience downtime during the year for maintenance and repairs.

Table 3-4. TEQ air emissions from medical waste incinerators (MWIs) for reference year 1987, 1995, and 2000

MWI class	No. of tested facilities/total	I-TEQ$_{DF}$ emission factor (ng/kg)	WHO$_{98}$ TEQ$_{DF}$ emission factor (ng/kg)	Activity level (kg/yr)	Annual I-TEQ$_{DF}$ emissions (g/yr)	Annual WHO$_{98}$ TEQ$_{DF}$ emissions (g/yr)
1987						
Uncontrolled	7/5,000	1,800	1,900	1.43E+09	2,600	2,700
Controlled	0			0	0	0
TOTAL				1.43E+09	2,600	2,700
1995						
Uncontrolled	7/1,770	1,800	1,900	2.54E+08	460	480
Controlled	12/605	50	51	5.17E+08	26	26
TOTAL				7.71E+08	490	510
2000						
Uncontrolled	7/975	1,800	1,900	1.98E+08	360	380
Controlled	12/333	50	51	4.03E+08	20	20
TOTAL				6.01E+08	380	400

4. COMBUSTION SOURCES OF CDDS/CDFS: POWER/ENERGY GENERATION

4.1. MOTOR VEHICLE FUEL COMBUSTION

This section covers on-road and off-road vehicles. The activity estimates were changed so that all are on a per-liter basis rather than a per-km driven basis, resulting in small changes in the air-release estimates. Other changes include addition of new literature studies, clarifications about derivations of emission factors, and discussions about the uncertainties associated with the estimates for off-road vehicles. Separate release estimates for 2-stroke engines (also referred to as 2-cycle engines) were considered, but insufficient information was available on both emission factors and activities to do this. The activity estimates are based on total fuel sold and include fuels used in all types of engines. Thus, 2-stroke engines are represented, and the uncertainties associated with their emissions are discussed. The confidence ratings for releases from all off-road vehicles were changed to preliminary due to lack of emissions test data. There were insufficient data to make an emission estimate for waste motor oil; see Section 4.3 for information on combustion of waste motor oil.

4.1.1. Air Literature

A number of additional studies on dioxin emissions from diesel engines were found as summarized below.

Gullett and Ryan (2002) characterized CDD/CDF emissions from two heavy duty diesel trucks under highway driving conditions and while idling: a 1989 Ford with a turbocharged Cummins engine and mechanical fuel controls and a 1990 Kenworth with a T800 engine equipped with the first generation of electronic fuel controls. The Ford trailer was loaded at 16,900 kg, and the Kenworth trailer at 8,400 kg. The Kenworth was tested using both a high mileage and the same engine in rebuilt, or "low mileage" condition. The average emission factors reported for each vehicle and driving condition are presented below:

- Ford/highway: 385 pg WHO_{98} TEQ/L
- Kenworth/highway (old engine): 58 pg WHO_{98} TEQ/L
- Kenworth/highway (rebuilt engine): 24 pg WHO_{98} TEQ/L
- Kenworth/idle: 6 pg WHO_{98} TEQ/L

Tests were also performed using a low-sulfur fuel, which was representative of U.S. diesel fuels in 2000.

Kim et al. (2003) conducted a study in Korea that measured CDD/CDF emissions from a light duty diesel engine under various loadings. The average CDD/CDFs concentrations per unit of exhaust gas with 25, 50, and 75% load rate are 14.5, 6.9, and 6.4 pg TEQ/Nm^3, respectively. According to the authors, these values, respectively, convert to 2.0, 0.6, and 0.5 pg TEQ/L fuel.

Norbeck et al. (1998) measured CDD/CDF emissions from a 6-cylinder, 310-hp diesel engine over the heavy-duty transient test cycle. Emission testing was conducted at the Los Angeles County Metropolitan Transportation Authority emission test facility. Dioxin sampling was conducted for the pre-1993 and reformulated fuels. Although PCDDs and PCDFs were detected, the most toxic isomers, 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF were not detected in either the pre-1993 or reformulated fuel. TEQ profiles were incomplete due to the low levels of CDD and PCDF detected in the emission samples.

Mayer et al (2003) reports on the use of fine-pored hot gas traps with filtration efficiencies exceeding 99% of the solid particles in the diesel exhaust gas. Catalyzed particle traps also achieve greater than 99% reduction in emissions of semi-volatile hydrocarbons (Laroo et al., 2011, CRC, 2009). This technology is used by original equipment manufacturers on new diesel exhaust systems and has been used to retrofit on-road and off-road engines in the U.S. Mayer et al testing with fuel borne catalysts indicate that in these situations, the large effective area of the filter, and the engine exhaust gas components in conjunction with the fuel borne catalysts can promote undesirable chemical reactions that release toxic secondary emissions. Dioxins and furans were found not to form in most trap systems but fuel-borne additives containing copper with extremely high fuel chlorine levels (up to 110 ppm), caused emissions to increase by four orders of magnitude. Copper fuel additives are not registered for use in the U.S. in on-road engines.

Laroo et al. (2011), Liu et al. (2011) and Hovemann et al. (2010) compared emissions of dioxins and furans using various catalyzed aftertreatment systems, including diesel oxidation catalysts, catalyzed diesel particulate filters, and copper and iron zeolite selective catalytic reduction (SCR) systems that are currently used in on-road diesel trucks in the U.S. These studies report no increase in dioxin or furan emissions when using catalyzed aftertreatment systems and fuel chlorine levels that were representative and one order of magnitude higher than what is currently in ultra low sulfur pump diesel fuel.

UNEP (2005) presents emission factors for a variety of engine types and fuels. These were originally presented in units of μg I-TEQ/MT and are converted to pg I-TEQ/L below (assumes diesel fuel has a density of 0.85 kg/L and gasoline has a density of 0.75 kg/L—Hazardous Substances Database, http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB.htm):

- Leaded gasoline, 4-stroke engine—1,600 pg I-TEQ/L
- Leaded gasoline, 2-stroke engine—2,600 pg I-TEQ/L
- Unleaded gasoline, 4-stroke engine without catalyst—75 pg I-TEQ/L
- Unleaded gasoline, 4-stroke engine with catalyst—0
- Unleaded gasoline, 2-stroke engine without catalyst—1,900 pg I-TEQ/L
- Diesel engines—85 pg I-TEQ/L

4.1.2. Air Emission Factor

In the original document, some of the emission factors were presented on a per-km driven basis and some on a per-liter of fuel basis. The present document changes all vehicle emission factors to a per-liter basis. Separate emission factors were developed for vehicles burning leaded gasoline, unleaded gasoline, and diesel fuel.

4.1.2.1. *Leaded Gasoline*

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 additives used in the fuel or motor oil (Ballschmiter et al., 1986; Marklund et al., 1990).

The average emission factor, as reported for the tailpipe emission studies performed using commercial leaded fuel (see Table 4-4 in U.S. EPA, 2006), was 532 pg WHO_{98} TEQ_{DF}/L (450 pg I-TEQ_{DF}/L), (Marklund et al., 1990; Hagenmaier et al., 1990; Schwind et al., 1991). This emission factor was applied to 1987 but was not needed for the other years due to the phaseout of leaded gasoline.

For application to off-road engines, this emission factor is considered preliminary because it is based on automobile testing and it is uncertain how well it applies to off-road engines (see discussion below).

4.1.2.2. *Unleaded Gasoline*

The literature documenting results of European studies indicates that CDD/CDF emissions from vehicles burning unleaded fuels are lower than emissions from vehicles burning leaded gas with chlorinated scavengers. It also appears, based on the limited data available, that catalyst-equipped cars have lower emission factors than do noncatalyst-equipped cars (Marklund et al., 1987; Marklund et al., 1990; Hagenmaier et al., 1990; Schwind et al., 1991). All automobiles running on unleaded gasoline in the United States are equipped with catalysts (commonly known as "catalytic converters"). The average emission factor reported for the tailpipe emission studies performed on catalyst-equipped cars (Hagenmaier et al., 1990; Schwind et al., 1991; Hutzinger et al., 1992) was calculated as 15.6 pg WHO_{98} TEQ_{DF}/L (14.9 pg I-TEQ_{DF}/L). This emission factor was assumed to apply to each reference year.

For application to off-road engines, this emission factor is considered preliminary because it is based on automobile testing, and it is uncertain how well it applies to off-road engines. Off-road engines can have very different designs. For example, few, if any, off-road gasoline engines have the mechanisms for fuel efficiency and emission control that on-road engines have, such as feedback control systems that monitor and correct the air-to-fuel ratio for combustion; either oxidation or three-way catalysts or exhaust gas recirculation systems (EGR); or overhead valves. Two-stroke engines are much more commonly used in off-road applications than on-road vehicles. The compression ratios for these engines are generally significantly less than those of four-stroke engines (U.S. EPA, 2002c). As a result, emissions of traditional pollutants from two-stroke engines are higher than from four-stroke engines. For example, EPA estimates emissions of PM from two-stroke, off-road motorcycles to be more than 20 times that of four-stroke motorcycles (U.S. EPA, 2002a). Although dioxin emissions do not always correspond to emissions of conventional pollutants, it is possible that two-stroke off-road engines have higher dioxin emissions. This belief is strongly reflected in the UNEP (2005) emission factor recommendations of 1,900 pg I-TEQ/L for unleaded gasoline in two-stroke engines without catalysts versus zero for unleaded gasoline in four-stroke engines with catalyst. The

UNEP (2005) recommendations for two-stroke engines were not adopted here due to the lack of supporting references.

4.1.2.3. *Diesel Fuel*

Data available upon which to base an evaluation of the extent of CDD/CDF emissions resulting from diesel fuel combustion are discussed in this section. These data address only emissions from on-road vehicles; no emissions data are available for off-road diesel uses (construction vehicles, farm vehicles, and stationary equipment).

Laroo et al. (2011) reported emission factors for a 2008 model year diesel engine of 1.89 pg I-TEQ/L without aftertreatment under steady-state operation; 1.28 pg I-TEQ/L for an engine with copper zeolite urea SCR, diesel oxidation catalyst, and catalyzed particulate filter aftertreatment under transient operation; and 0.21 pg I-TEQ/L for an engine equipped with a diesel oxidation catalyst and catalyzed particulate filter under transient operation. Liu et al. (2011) reported emission factors for a 2010 model year diesel engine of 0.31 pg WHO 1998 TEQ/hp-hr without aftertreatment; 0.12 pg WHO 1998 TEQ/hp-hr for an engine with copper zeolite urea SCR, diesel oxidation catalyst, and catalyzed particulate filter aftertreatment and 0.13 pg WHO 1998 TEQ/hp-hr for an engine equipped with a diesel oxidation catalyst and catalyzed particulate filter under steady-state operation. Hovemann et al. (2010) reported emissions factors of 0.11 pg/m^3 for steady-state operation and 0.10 pg/m^3 for transient operation of a diesel engine with aftertreatment including a diesel oxidation catalyst, copper zeolite SCR and urea. The Health Effects Institute (2009) reported a range of emissions from 0.13 – 1.4 pg I-TEQ/L for three diesel engines equipped with catalyzed particulate filters.

Although aggregate samples representing several thousand heavy-duty diesel vehicles were collected in Oehme et al. (1991), several characteristics of the study introduce considerable uncertainty with regard to the use of the study's results as a basis for estimating emissions in the United States: (a) heavy-duty vehicles represented only 3 to 19% of total vehicle traffic in the tunnel; (b) the majority of the light-duty vehicles were fueled with leaded gasoline, which can lead to increased releases of CDD/CDFs; and (c) technology differences likely existed between the 1988 Norwegian and the 1987 and 1995 U.S. vehicle fleets.

The tunnel study conducted in Baltimore, MD, by Gertler et al. (1996, 1998) shares the disadvantages of all tunnel studies relative to those that directly measured CDDs and CDFs in tailpipe emissions. Specifically, tunnel studies rely on indirect measurements (rather than tailpipe measurements), which may introduce bias, and the emission factors calculated from these studies reflect the mix of vehicles using the tunnel—and not necessarily the overall vehicle fleet. Also, they reflect the driving conditions of the tunnel (surface slope, speed, braking, etc.), which may not be representative of usual driving conditions.

However, the Gertler et al. (1996, 1998) study does have strengths that are lacking in the Oehme et al. (1991) tunnel study, and it has advantages over the two U.S. diesel truck tailpipe studies, including: (a) the study was conducted during the reference year time frame (1995) in the United States and, thus, reflects U.S. fuels and technology of that time period, (b) virtually no vehicle using the tunnel was fueled with leaded gasoline, (c) the tunnel walls and streets were cleaned one week prior to the start of sampling and, in addition, the study analyzed road dust and determined that resuspended road dust contributed only about 4% of the estimated emission factors, (d) the heavy-duty vehicles comprised, on average, a relatively large proportion (25.7%) of vehicles using the tunnel, and (e) a large number of heavy-duty vehicles—approximately 33,000—passed through the tunnel during the sampling period, which generates confidence that the emission factor is representative of interstate trucks. It should be noted, though, that the study was most representative of heavy duty trucks because these were the primary type of vehicle using the tunnel. For other diesel vehicles (e.g., light duty trucks, automobiles, buses), the study is less representative, and uncertainty is greater.

Considering the strengths and weaknesses of the available emission factor data from the tailpipe and tunnel studies, the mean TEQ emission factor reported by Gertler et al. (1996, 1998)—182 pg WHO_{98} TEQ_{DF}/km (172 pg I-TEQ_{DF}/km)—is assumed to represent the best current estimate of the average emission factor for on-road diesel-fueled vehicles. This emission factor was converted to a per-liter basis assuming a fuel efficiency of 2.98 km/L (U.S. EPA, 2003a). This yields an emission factor of 540 pg WHO_{98} TEQ_{DF}/L (510 pg I-TEQ_{DF}/L), which was assumed to apply to all reference years for both on-road and off-road vehicles. It is likely that the fleet average emission factor has decreased over the reference years (due to improvements in engine/emission designs), but insufficient information was available to account for this. For application to off-road vehicles, the factor is considered preliminary because it is based on truck testing, and it is uncertain how well it applies to other types of diesel vehicles such as heavy duty vehicles used in construction, tractors, off-road military vehicles, ships, and locomotives.

4.1.3. Air Activity Level

The activity estimates for internal combustion engines were derived on the basis of fuel consumed as reported by the Energy Information Administration (EIA, 2008a).

4.1.3.1. *Gasoline*

EIA (2008a) provides data on the total "motor gasoline product supplied," which represents all gasoline consumed in the United States. These data were reported as barrels per year and are converted here to liters by multiplying by 42 gal/barrel and 3.78 L/gal. For 1987, it is assumed that 24% of the gasoline was leaded (1.00×10^{11} L) and the remainder unleaded (3.18×10^{11} L) (EIA, 1993). For years 1995 and 2000, it is assumed that leaded gasoline was produced in negligible amounts. The total amount of unleaded gasoline consumed in 1995 was 4.00×10^{11} L, and the total amount consumed in 2000 was 4.93×10^{11} L. EIA does not provide data that allow the gasoline uses to be divided between on road and off road. However, U.S. EPA (2006) provided estimates for the year 2000 suggesting that 5% of the gasoline was used for off-road engines (kilometers driven on road were converted to liters, assuming an average fuel efficiency of 10 km/L). This percentage was assumed to apply to all reference years, resulting in the following estimates:

	Leaded (L)			**Unleaded (L)**		
	Total	**On-road**	**Off-road**	**Total**	**On-road**	**Off-road**
1987	1.00×10^{11}	9.5×10^{10}	0.5×10^{10}	3.18×10^{11}	3.03×10^{11}	0.15×10^{11}
1995	0	0	0	4.00×10^{11}	3.80×10^{11}	0.20×10^{11}
2000	0	0	0	4.93×10^{11}	4.68×10^{11}	0.25×10^{11}

4.1.3.2. *Diesel*

EIA provides data on "distillate fuel oil product supplied," which represents all distillate fuel consumed in the United States. Distillate fuel includes diesel and other fuels used primarily for space heating. The diesel portion of the distillate fuel was determined using EIA data on "sales of distillate fuel oil by end use." For 2001, these data suggest the following:

- Diesel fuel used on road is 55% of the total.
- Diesel fuel used off road (includes off-highway, farm, railroad, vessels, and military categories) is 20% of the total.
- Other uses of distillate fuels (includes residential, commercial, industrial, and electric power categories) make up 25% of the total.

It is assumed that these percentages for 2001 apply to all reference years. Applying these to the "distillate fuel oil product supplied," yields:

- 1987—9.48×10^{10} L on road, 3.45×10^{10} L off road
- 1995—1.02×10^{11} L on road, 3.71×10^{10} L off road
- 2000—1.19×10^{11} L on road, 4.32×10^{10} L off road

4.1.4. Air Releases

Air-release estimates were made by multiplying the emission factors with the activity estimates. Separate release estimates were made for leaded gasoline, unleaded gasoline, diesel off road, and diesel on road.

4.1.5. Water Releases—None

4.1.6. Solid Residue Releases

Solid residue releases could result from disposal/recycling of mufflers or catalytic converters. No information could be found on the possible CDD/CDF content of these materials.

4.1.7. Products—None

4.1.8. Release Summary

The inventory decision criteria and release estimates to all media are summarized below:

Inventory Decision Criteria for Motor Vehicle Combustion—On-road				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Inventory Decision Criteria for Motor Vehicle Combustion—Off-road				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Motor Vehicle Combustion
Air Releases

Emission Factors

Leaded Gasoline

- 1987—530 pg WHO_{98} TEQ_{DF}/L (450 pg I-TEQ_{DF}/L) (Preliminary for off-road).

Unleaded Gasoline

- 1987—16 pg WHO_{98} TEQ_{DF}/L (15 pg I-TEQ_{DF}/L) (Preliminary for off-road).
- 1995—16 pg WHO_{98} TEQ_{DF}/L (15 pg I-TEQ_{DF}/L) (Preliminary for off-road).
- 2000—16 pg WHO_{98} TEQ_{DF}/L (15 pg I-TEQ_{DF}/L) (Preliminary for off-road).

Diesel

- 1987—540 pg WHO_{98} TEQ_{DF}/L (510 pg I-TEQ_{DF}/L) (Preliminary for off-road).
- 1995—540 pg WHO_{98} TEQ_{DF}/L (510 pg I-TEQ_{DF}/L) (Preliminary for off-road).
- 2000—540 pg WHO_{98} TEQ_{DF}/L (510 pg I-TEQ_{DF}/L) (Preliminary for off-road).

Activity Levels

Leaded Gasoline, On-road

- 1987—9.5×10^{10} L/yr.

Leaded Gasoline, Off-road

- 1987—0.5×10^{10} L/yr.

Unleaded Gasoline, On-road

- 1987—3.03×10^{11} L/yr.
- 1995—3.80×10^{11} L/yr.
- 2000—4.68×10^{11} L/yr.

Unleaded Gasoline, Off-road

- 1987—3.18×10^{11} L/yr.
- 1995—4.00×10^{11} L/yr.
- 2000—4.93×10^{11} L/yr.

Diesel, On-road

- 1987—0.15×10^{10} L/yr.
- 1995—0.20×10^{11} L/yr.
- 2000—0.25×10^{11} L/yr.

Diesel, Off-road

- 1987—3.45×10^{10} L/yr.
- 1995—3.71×10^{10} L/yr.
- 2000—4.32×10^{10} L/yr.

Motor Vehicle Combustion (continued)
Releases ***Leaded Gasoline, On--road*** • 1987—50 g WHO_{98} TEQ_{DF} (43 g I-TEQ_{DF}) ***Leaded Gasoline, Off--road*** • 1987—3 g WHO_{98} TEQ_{DF} (2 g I-TEQ_{DF}) (Preliminary). ***Unleaded Gasoline, On-road*** • 1987—5 g WHO_{98} TEQ_{DF} (5 g I-TEQ_{DF}). • 1995—6 g WHO_{98} TEQ_{DF} (6 g I-TEQ_{DF}). • 2000—7 g WHO_{98} TEQ_{DF} (7 g I-TEQ_{DF}). ***Unleaded Gasoline, Off-road*** • 1987—0.2 g WHO_{98} TEQ_{DF} (0.2 g I-TEQ_{DF}) (Preliminary). • 1995—0.3 g WHO_{98} TEQ_{DF} (0.3 g I-TEQ_{DF}) (Preliminary). • 2000—0.4 g WHO_{98} TEQ_{DF} (0.4 g I-TEQ_{DF}) (Preliminary). ***Diesel, On-road*** • 1987—51 g WHO_{98} TEQ_{DF} (48 g I-TEQ_{DF}). • 1995—55 g WHO_{98} TEQ_{DF} (52 g I-TEQ_{DF}). • 2000—64 g WHO_{98} TEQ_{DF} (61 g I-TEQ_{DF}). ***Diesel, Off-road*** • 1987—19 g WHO_{98} TEQ_{DF} (18 g I-TEQ_{DF}) (Preliminary). • 1995—20 g WHO_{98} TEQ_{DF} (19 g I-TEQ_{DF}) (Preliminary). • 2000—23 g WHO_{98} TEQ_{DF} (22 g I-TEQ_{DF}) (Preliminary).
Water Releases
No information was found suggesting that water releases from internal combustion engines would contain CDDs and CDFs.
Solid Residue Releases
No information was found suggesting that solid residue releases from internal combustion engines would contain CDDs and CDFs.
Products
None.

4.2. WOOD COMBUSTION

4.2.1. Residential Wood Combustion

Several new literature studies were added, but no changes were made to the estimates of air releases from traditional residential wood-burning fireplaces and stoves. New sections were developed on the air releases from outdoor wood-fired boilers and on solid residues from all forms of residential wood burning.

This section focuses on residential burning of natural untreated wood. It should be noted though, that treated wood may be burned at some residences with the potential for increased CDD/CDF emissions. Wevers et al. (2003) measured CDD/CDF emissions from domestic wood-burning appliances and reported emission factors of 22.4 ng I-TEQ/kg for burning untreated wood and 1,702 ng I-TEQ/kg for burning treated wood. Tame et al. (2003) measured CDD/CDF levels in ash from wood combustion in a cone calorimeter. Ash from burning untreated pine had an average of 0.050 ng I-TEQ/kg ash. For the CCA (chromated copper arsenate) treated pine, burnt under identical conditions, a significant increase was observed, with an average of 35 ng I-TEQ/kg. Tame et al. (2007) reviewed the literature on the role of preservatives in the formation of dioxin in the combustion of wood. They conclude that current and emerging wood preservatives significantly increase dioxin formation during combustion in domestic stoves and in fires. Not all investigators, however, have observed these increases. Wasson et al. (2005) conducted chamber tests to measure CDD/CDF emissions from burning CCA treated wood. Emission factors ranged from 1.4 to 2.3 ng WHO_{98} TEQ/kg, which are similar to those for untreated wood.

4.2.1.1. *Air Releases from Indoor Residential Wood Burners*

A study conducted in Australia by Gras et al. (2002) measured dioxin emissions from a variety of wood-burning appliances and wood types. The average values for various wood types were 7.5 ng WHO_{98} TEQ/kg for eucalyptus, 19 ng WHO_{98} TEQ/kg for manufactured wood, and <1 ng WHO_{98} TEQ/kg for softwoods.

Gullett et al. (2003) measured dioxin emissions from residential fireplace and woodstove appliances burning fuels available from the San Francisco Bay area. Common California natural firewoods and manufactured artificial logs were tested under operating conditions intended to reflect domestic use patterns in the Bay area, which are primarily episodic burning for aesthetic reasons. Average CDD/CDF emissions factors ranged from 0.25 to 1.4 ng WHO_{98} TEQ/kg of wood burned for natural wood fuels and 2.4 ng WHO_{98} TEQ/kg for artificial logs.

Pfeiffer et al. (2000) measured CDD/CDF emissions from wood fired household appliances used in Germany. Emission factors ranged from 0.141 to 0.785 ng I-TEQ/kg.

Wevers et al. (2003) measured CDD/CDF emissions from domestic wood burning appliances used in Belgium. The average emission factor was 22.4 ng I-TEQ/kg for burning untreated wood.

UNEP (2005) recommended an emission factor of 100 μg I-TEQ/TJ (TJ = terajoule or 10^{12} joule) for virgin biomass-fired stoves. Assuming that wood combustion produces 12−15 MJ/kg where MJ = megajoule or 10^6 joule (UNEP, 2005), this converts to 1.2 to 1.5 ng I-TEQ/kg of wood burned.

The emission factor selected for indoor residential wood burning was based on Environment Canada (2000) because these tests took place in North America using indigenous wood, and they included the analysis of an EPA-certified wood stove. The mean value of the Environment Canada study (0.5 ng I-TEQ/kg wood or ng WHO_{98} TEQ/kg wood) was applied to all reference years.

Activity estimates were derived from EIA (2008b), which reports energy production from residential wood burning in BTUs. These were converted to mass of wood burned by dividing these values by 14,080 BTU/kg (average heat value of seasoned wood at 20% moisture—ORNL, 2008). This yields estimates of 71 MMT in 1987, 37 MMT in 1995 and 30 MMT in 2000.

4.2.1.2. *Air Releases from Residential Outdoor Wood-Fired Boilers*

Outdoor wood-fired boilers (OWBs) are wood-fired furnaces used for heating, typically in residential settings. They are located some distance from the house, usually in an insulated shed. Each OWB houses an oversized firebox surrounded by a water jacket. Water is circulated through the jacket and piped underground to deliver hot water for space heating and domestic use. OWBs are designed to burn large amounts of wood over extended periods of time; fireboxes range in size from 20 ft^3 to 150 ft^3 and can heat buildings up to 20,000 ft^2. They can produce from 115,000 BTU/hour up to 3.2 million BTU/hour, although most residential installations are less than 1 million BTU/hour (NESCAUM, 2006).

Because OWBs operate in a cyclic fashion, they can produce large amounts of smoke. When an OWB is in the "off" cycle and does not need to generate heat, the air damper closes to cut off the air supply. This creates an oxygen-starved environment in which the fire smolders, creating smoke and creosote that condenses on the internal steel surfaces. When heat needs to be produced, the air damper opens and natural draft forces air into the firebox, pushing the smoke and air pollutants out the stack. Measured emissions peak when the unit has received a fresh load of fuel and the wood has not yet reached a charcoal stage. In the field test conducted by NESCAUM, the unit's internal stack temperature never reached levels that would have resulted in complete combustion. In comparing emissions of particulate matter (PM) from various sources, it was noted that one OWB can emit as much PM as four heavy duty diesel trucks. Generally, OWBs do not use catalytic or noncatalytic emission control devices commonly employed by other residential combustion devices (NESCAUM, 2006).

OWBs have not been tested for CDD/CDF emissions. Their cyclic air flow and low operating temperatures (see discussion above), suggests that their emissions may be best represented by a value near the upper end of measurements for natural wood burned in wood stoves. Accordingly, an emission factor of 20 ng WHO_{98} TEQ_{DF}/kg wood (based on Wevers et al., 2003) is used to represent OWBs. This emission factor is assigned a preliminary confidence rating because it is not based on testing of actual OWBs.

EPA estimates that there were more than 100,000 OWBs in use in the United States in 2007; NESCAUM estimates that more than 155,000 units have been sold since 1990 (U.S. EPA, 2007a). An average household in the Northeast (where many of these units are used) consumes 63.1 million BTU per year for space heating (EIA, 2001). Multiplying this value by the 100,000 OWBs in use suggests they produced a total of 6.3 trillion BTU in 2007. Dividing this value by 14,080 BTU per kilogram (the average heat value of seasoned wood at 20% moisture [ORNL, 2008]) yields a total wood consumption of 448,000 MTs in 2007, and this is assumed to apply to 2000. Because it is not known how many units were in operation in 1987 and 1995, the activity level could not be estimated for these years.

This procedure assumes that all OWBs supply 100% of a home's space heating needs, which may lead to an overestimate of wood consumed. The assumption that the 2007 activity value applies to 2000 also leads to an overestimate. However, the assumption that only seasoned wood is burned, when in fact unseasoned wood may also be used, would underestimate the amount of wood consumed. It is unclear to what extent these uncertainties offset each other.

4.2.1.3. *Water Releases—None*

4.2.1.4. *Solid Residues from All Residential Wood Burning*

EPA (2006) summarizes studies measuring CDDs/CDFs in chimney soot from wood-burning stoves and fireplaces by several researchers (Bumb et al., 1980; Nestrick and Lamparski, 1982, 1983; Clement et al., 1985; Bacher et al., 1992; Van Oostam and Ward, 1995; Dumler-Gradl et al., 1995). The CDD/CDF levels ranged from 80 to 350 ng WHO_{98} TEQ/kg.

Wunderli et al. (1996) measured CDD/CDF levels in ash of wood-burning facilities in Switzerland. The facilities were characterized as small-to-medium sized, but they were not described in detail. Some of them had air pollution controls and may have been more sophisticated than most residential wood stoves. The mean level for natural wood burning was 2.5 ng I-TEQ/kg of fly ash ($n = 6$) and 5.3 ng I-TEQ/kg of bottom ash ($n = 8$). UNEP (2005) used this reference to support their recommendation of 10 ng I-TEQ/kg of ash residue from biomass-fired stoves.

4.2.1.5. *Solid Residue Emission Factor*

The CDD/CDF levels in soot are likely to be higher than bottom ash from wood burning, so the soot based studies noted above were not used to select an emission factor. Instead, the UNEP (2005) recommendation of 10 ng I-TEQ/kg of ash residue (based on Wunderli et al., [1996] data for wood-burning bottom ash) was selected as the best for residential wood burning. The congener profile for bottom ash from natural wood burning reported by Wunderli et al. (1996) indicated that the WHO_{98} TEQs were only about 4% greater than the I-TEQs. On this basis, the UNEP recommendation can also be expressed as 10 ng WHO_{98} TEQ/kg of ash residue.

4.2.1.6. *Solid Residue Activity Level*

The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to 8% ash (Ragland et. al, 1991). A mid-range value of 3% is assumed here for all wood burned. Multiplying this percentage by the amount of wood consumed (as reported above) yields the ash production amounts for each reference year: 2.13 MMT in 1987, 1.11 MMT in 1995, and 0.9 MMT in 2000.

4.2.1.7. *Solid Residue Releases*

Solid residue releases were estimated by multiplying the ash emission factor by the ash activity level. These release estimates include both indoor and outdoor sources of residential wood combustion. Some ash from residential wood combustion is disposed with household garbage that is sent to municipal landfills. This portion of the ash would not be considered a release to the open environment. The remainder is land disposed in a manner that is assumed to be releasable to the environment. One study reported that approximately 80% of all ash is land applied in the Northeast United States, less than 10% is land applied in the Southeast (University of Georgia, 2002). Because the portion going to a landfill is probably small, it is assumed here that all of the ash releases can be considered an environmental release.

4.2.1.8. *Release Summary*

The inventory decision criteria and release estimates to all media are summarized below:

Inventory Decision Criteria for Indoor Residential Wood Burners				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		Q	

Residential Wood Combustion

Air Releases

Emission Factor

Indoor Residential Wood Burners

- 1987—0.5 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of wood.
- 1995—0.5 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of wood.
- 2000—0.5 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of wood.

Outdoor Wood-Fired Boilers

- 1987—20 ng WHO_{98} TEQ_{DF}/kg of wood (Preliminary).
- 1995—20 ng WHO_{98} TEQ_{DF}/kg of wood (Preliminary).
- 2000—20 ng WHO_{98} TEQ_{DF}/kg of wood (Preliminary).

Activity Level

Indoor Residential Wood Burners

- 1987—71 MMT.
- 1995—37 MMT.
- 2000—30 MMT.

Outdoor Wood-Fired Boilers

- 1987—Not Available.
- 1995—Not Available.
- 2000—0.448 MMT (Preliminary).

Releases

Indoor Residential Wood Burners

- 1987—36 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}).
- 1995—19 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}).
- 2000—15 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}).

Outdoor Wood-Fired Boilers

- 1987—Not Available
- 1995—Not Available
- 2000—9 g WHO_{98} TEQ_{DF} (Preliminary).

Water Releases

None.

Residential Wood Combustion (continued)
Solid Residue Releases
Emission Factors • 1987—10 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of ash. • 1995—10 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of ash. • 2000—10 ng WHO_{98} TEQ_{DF}/kg (I-TEQ_{DF}/kg) of ash.
Activity Levels • 1987—2.13 MMT of ash. • 1995—1.11 MMT of ash. • 2000—0.9 MMT of ash.
Releases • 1987—21 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 1995—11 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 2000—9 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}).
Products
None.

4.2.2. Industrial Wood Combustion

4.2.2.1. *Air Releases*

No changes were made to the emission factor estimates for industrial burning of salt and nonsalt laden wood. However, an additional study is discussed below which shows that combustion temperature and wood condition can have a large impact on emission factors.

Yasuhara et al. (2003) measured CDD/CDF emissions from a wood burning incinerator in Japan. With combustion temperature of about 600EC, the following emission factors (ng WHO_{98} TEQ/kg) were measured: pine—167, cedar—164, seawater impregnated pine—392, seawater impregnated cedar bark—559 and seawater impregnated cedar without bark—828. Much lower emission factors were measured when the combustion temperature was increased to 800EC: pine—2.3, beech—3.5, chlordane impregnated waste wood—40 and pentachlorophenol impregnated waste wood—44.

For nonsalt laden wood, the mean of the emission factors derived from the four CARB studies and five NCASI studies (assuming nondetect values were zero) is 0.6 ng WHO_{98} TEQ_{DF}/kg wood (0.56 ng I-TEQ_{DF}/kg wood) and is used in this document as the most representative of industrial wood combustion for all reference years.

NCASI (1995) concluded that CDD/CDF emissions from facilities burning salt-laden wood residue may be considerably higher than those from facilities burning salt-free wood. The overall average of the five tested facilities in Canada (Luthe et al., 1998) and the United States (U.S. EPA, 1987), 13.2 ng I-TEQ_{DF}/kg of wood, was applied to all three reference years. Based on the congener profile reported by Luthe et al. (1998), this converts to 15.3 ng WHO_{98} TEQ/kg.

Similarly, no change was made to the activity estimate for salt laden wood. However, the activity estimate for nonsalt laden wood was changed for all years to reflect more recent data in EIA (2008c). Values are reported in the release summary below.

4.2.2.2. *Water Literature—None*

4.2.2.3. *Solid Residue Releases*

As indicated in U.S. EPA (2006), the ash concentrations from the NCASI Handbook (13.2 ng WHO_{98} TEQ_{DF}/kg) appears to fall within the range of values reported in the various studies and a reasonable value for mixed bottom and fly ash. Oeheme and Muller (1995) measured CDD/CDF levels in ash from wood-fired boilers in Switzerland. The levels in bottom ash were on the order of 1 ng I-TEQ/kg when natural wood was incinerated. However, in filter ash the levels were about two orders of magnitude higher. Burning of waste wood from house demolition and construction resulted in concentrations in the range of 1–10 ng I-TEQ/kg.

The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to 8% ash (Ragland et al, 1991). A mid-range value of 3% is assumed here for all wood burned. Multiplying this percentage by the amount of wood consumed (as reported in the release summary below) yields the ash production amounts for each reference year: 3.48 MMT in 1987, 3.51 MMT in 1995, and 3.48 MMT in 2000.

All ash from industrial wood combustion is assumed to be disposed in a secure landfill and is, therefore, not considered an environmental release. However, the amounts of dioxin in landfilled ash from industrial wood burning can be estimated by multiplying the ash concentration and ash amounts presented above. This yields the following estimates:

- 1987—46 g WHO_{98} TEQ_{DF}/kg
- 1995—46 g WHO_{98} TEQ_{DF}/kg
- 2000—46 g WHO_{98} TEQ_{DF}/kg

4.2.2.4. *Release Summary*

The inventory decision criteria and release estimates to all media are summarized below:

Inventory Decision Criteria for Industrial Wood Combustion				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Industrial Wood Combustion

Air Releases

Emission Factor

Nonsalt-Laden Wood

- 1987—0.6 ng WHO_{98} TEQ_{DF}/kg (0.56 ng I-TEQ_{DF}/kg) of wood.
- 1995—0.6 ng WHO_{98} TEQ_{DF}/kg (0.56 ng I-TEQ_{DF}/kg) of wood.
- 2000—0.6 ng WHO_{98} TEQ_{DF}/kg (0.56 ng I-TEQ_{DF}/kg) of wood.

Salt-Laden Wood

- 1987—15 ng WHO_{98} TEQ/kg (13 ng I-TEQ_{DF}/kg) of wood.
- 1995—15 ng WHO_{98} TEQ/kg (13 ng I-TEQ_{DF}/kg) of wood.
- 2000—15 ng WHO_{98} TEQ/kg (13 ng I-TEQ_{DF}/kg) of wood.

Activity Level

Nonsalt-Laden Wood

- 1987—116 MMT.
- 1995—117 MMT.
- 2000—116 MMT.

Salt-Laden Wood

- 1987—0.5 MMT.
- 1995—0.5 MMT.
- 2000—0.8 MMT.

Releases

Nonsalt-Laden Wood

- 1987—70 g WHO_{98} TEQ_{DF} (65 g I-TEQ_{DF}).
- 1995—70 g WHO_{98} TEQ_{DF} (65 g I-TEQ_{DF}).
- 2000—70 g WHO_{98} TEQ_{DF} (65 g I-TEQ_{DF}).

Salt-Laden Wood

- 1987—8 g WHO_{98} TEQ_{DF} (7 g I-TEQ_{DF}).
- 1995—8 g WHO_{98} TEQ_{DF} (7 g I-TEQ_{DF}).
- 2000—12 g WHO_{98} TEQ_{DF} (10 g I-TEQ_{DF}).

Total Industrial Releases

- 1987—78 g WHO_{98} TEQ_{DF} (72 g I-TEQ_{DF}).
- 1995—78 g WHO_{98} TEQ_{DF} (72 g I-TEQ_{DF}).
- 2000—82 g WHO_{98} TEQ_{DF} (75 g I-TEQ_{DF}).

Water Releases

None.

Solid Residue Releases

All ash is assumed to be landfilled and, therefore, is not considered to be an environmental release.

Industrial Wood Combustion (continued)
Products
None.

4.3. OIL COMBUSTION

Section 4.1 covered combustion of gasoline and diesel fuels in engines. This section addresses the combustion of other types of distillate oil products and residual fuel oils. These products are burned primarily in furnaces or boilers in both residential/institutional settings and in large industrial facilities. Distillate fuel oils are distilled from crude oil. Residual oils are what remain of the crude oil after gasoline, and the distillate fuel oils are extracted through distillation. Residual and distillate oils are further distinguished by grade: Numbers 1 and 2 are distillate oils. No. 1 is similar to kerosene and is the fraction that boils off right after gasoline. No. 2 is the diesel that trucks and some cars run on, leading to the name "road diesel"; this category is addressed in Section 4.1.

Fuel Grades 5 and 6 are residual oils and sometimes referred to as "heavy fuel oils." Number 6 fuel oil is sometimes referred to as Bunker C. Fuel Grade 4 is either distillate oil or a mixture of distillate and residual oils. Distillate oils are more volatile and less viscous than residual oils, which have negligible nitrogen and ash content, and usually contain less than 0.3% sulfur (by weight). Distillate oils are used mainly in domestic and small commercial applications. The heavier residual oils (Grades 5 and 6), being more viscous and less volatile than distillate oils, must be heated for ease of handling and to facilitate proper atomization. Because residual oils are produced from the residue after the lighter fractions are removed from the crude oil, they may contain significant quantities of ash, nitrogen, and sulfur.

4.3.1. Institutional/Commercial and Residential Oil Combustion

4.3.1.1. *Air Releases*

No changes were made to the emission factors. No testing for CDD/CDF emissions from commercial or residential oil-fired combustion units in the United States could be located. However, EPA (1997a) estimated CDD/CDF congener group and TEQ emission factors using average CDD/CDF concentrations reported for soot samples from 21 distillate fuel oil-fired furnaces used for central heating in Canada and a PM emission factor for distillate fuel oil combustors (300 mg/L oil) obtained from AP-42 (U.S. EPA, 1995a). The TEQ emission factor estimate—0.19 ng WHO_{98} TEQ_{DF}/L of oil (0.15 ng I-TEQ_{DF}/L of oil)—was derived using the calculated emission factors for 2,3,7,8-TCDD, 2,3,7,8-TCDF, and the 10 congener groups. These results are near the upper end of the range from Pfeiffer et al. (2000) who measured CDD/CDF emissions from oil fired household appliances used in Germany. Emission factors were in the range of 0.025 to 0.135 ng I-TEQ/kg.

Minor updates were made to the activity estimates. EIA (2008a) data were used to derive the activity levels. EIA supplied yearly data on total distillate fuel oil and total residual fuel oil supplied in the United States. EIA also provided a breakdown of fuel oil sales by sector for the years back to 2001. The sector percentages for 2001 were assumed to apply to each of the reference years. These percentages were multiplied by the totals (also used conversion factors of 42 gal/barrel and 3.79 L/gal) to estimate the amount of distillate fuel oil consumed in the residential and commercial sectors. On this basis, the following estimates were made for each reference year: 1987—29.4 billion L, 1995—31.7 billion L, and 2000—36.9 billion L.

4.3.1.2. *Water Releases—None*

4.3.1.3. *Solid Residue Releases—None*

4.3.1.4. *Products—None*

4.3.1.5. *Release Summary*

The inventory decision criteria and release estimates are summarized below:

Inventory Decision Criteria for Institutional/Commercial and Residential Oil Combustion				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Institutional/Commercial and Residential Oil Combustion
Air Releases
Emission Factors • 1987—190 pg WHO_{98} TEQ_{DF}/L (150 pg I-TEQ_{DF}/L) of oil combusted. • 1995—190 pg WHO_{98} TEQ_{DF}/L (150 pg I-TEQ_{DF}/L) of oil combusted. • 2000—190 pg WHO_{98} TEQ_{DF}/L (150 pg I-TEQ_{DF}/L) of oil combusted.
Activity Levels • 1987—29.4 billion L. • 1995—31.7 billion L. • 2000—36.9 billion L.
Releases • 1987—6 g WHO_{98} TEQ_{DF} (4 g I-TEQ_{DF}). • 1995—6 g WHO_{98} TEQ_{DF} (5 g I-TEQ_{DF}). • 2000—7 g WHO_{98} TEQ_{DF} (6 g I-TEQ_{DF}).
Water Releases
These facilities do not have wastewater releases.
Solid Residue Releases
These facilities do not have solid releases.
Products
None.

4.3.2. Utility Sector and Industrial Oil Combustion

Minor changes were made to the activity estimates as explained below.

4.3.2.1. *Air Literature*

In 1993, the Electric Power Research Institute (EPRI) sponsored a project to gather information of consistent quality on power plant emissions. The Field Chemical Emissions Measurement (FCEM) project included testing of two cold-sided, ESP-equipped, oil-fired power plants for CDD/CDF emissions. EPA (1997a) reports on testing at oil fired utility boilers for a variety of furnace configurations and APCDs.

Some boilers use low-NOx burners, which reduce flame turbulence, delay fuel/air mixing, and establish fuel-rich zones within the boiler during initial combustion. The longer, less intense flames that result from the altered combustion lower flame temperatures and reduce thermal NOx formation (Colburn, 1996), Because low-NOx burners reduce temperatures and, thus, the completeness of combustion the potential exists for increased CDD/CDF formation. However, this has not yet been evaluated via stack testing.

4.3.2.2. *Air Emission Factor*

EPA (2006) based the emission factor on the average of the EPRI (1994) and EPA (1997a) studies. The emission factor—230 pg WHO_{98} TEQ_{DF}/L oil combusted (200 pg I-TEQ_{DF}/L oil combusted)—was applied to all three reference years.

4.3.2.3. *Activity Level*

Updated EIA data were used to derive the activity levels. EIA supplied yearly data on total distillate fuel oil and total residual fuel oil supplied in the United States. EIA also provided a breakdown of fuel oil sales by sector for the years back to 2001. The sector percentages for 2001 were assumed to apply to each of the reference years. Multiplying these percentages by the totals yields the following estimates for each reference year (also used conversion factors of 42 gal/barrel and 3.79 L/gal):

Distillate Fuel Oil—Industrial and Electric Power Use

- 1987—10.4 billion L
- 1995—11.2 billion L
- 2000—13.0 billion L

Residual Fuel Oil—Total

- 1987—73.4 billion L
- 1995—49.5 billion L
- 2000—53.0 billion L

4.3.2.4. *Air Releases*

The air releases were estimated by multiplying the emission factor and activity estimates.

4.3.2.5. *Water Releases—None*

4.3.2.6. *Solid Residue Releases—None*

4.3.2.7. *Products—None*

4.3.2.8. *Release Summary*

The inventory decision criteria and release estimates are summarized below:

Inventory Decision Criteria for Utility Sector and Industrial Oil Combustion				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Utility Sector and Industrial Oil Combustion
Air Releases
Emission Factors • 1987—230 pg WHO_{98} TEQ_{DF}/L (200 pg I-TEQ_{DF}/L) of oil combusted. • 1995—230 pg WHO_{98} TEQ_{DF}/L (200 pg I-TEQ_{DF}/L) of oil combusted. • 2000—230 pg WHO_{98} TEQ_{DF}/L (200 pg I-TEQ_{DF}/L) of oil combusted.
Activity Level • 1987—83.8 billion L. • 1995—60.7 billion L. • 2000—66.0 billion L.
Releases • 1987—19 g WHO_{98} TEQ_{DF} (17 g I-TEQ_{DF}). • 1995—14 g WHO_{98} TEQ_{DF} (12 g I-TEQ_{DF}). • 2000—15 g WHO_{98} TEQ_{DF} (13 g I-TEQ_{DF}).
Water Releases
These facilities do not have wastewater releases.
Solid Residue Releases
These facilities do not have solid releases.
Products
These facilities do not have products.

4.3.3. Waste Oil Combustion

Waste oil includes used crankcase oils from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids). When discarded, these oils become waste oils due to a breakdown of physical properties and contamination by the materials they come in contact with. The different types of waste oils may be burned as mixtures or as single fuels where supplies allow. Waste, or used, oil can be burned in a variety of combustion systems including industrial boilers; commercial/institutional boilers; space heaters; asphalt plants; cement and lime kilns; other types of dryers and calciners; and steel-production blast furnaces (U.S. EPA, 1998c). USDOE (2006) reports the following breakout for 2006 in billions of gallons:

Asphalt Plants - 0.286
Space Heaters - 0.113
Industrial Boilers - 0.093
Utility Boilers - 0.080

Steel Mills - 0.080
Cement Kilns - 0.033
Others - 0.095 (includes: marine boilers, pulp & paper mills, commercial boilers)

Total - 0.780

CDD/F emissions from all of these facility types except space heaters were covered in other parts of this document. So this section will address only releases from space heaters.

4.3.3.1. *Air Literature*

Bremmer et al. (1994) measured the CDD/CDF emissions from the combustion of used oil by small combustion units in the Netherlands. Flue gases from a garage stove consisting of an atomizer fueled by spent lubricating oil from diesel engines (35 mg $Cl^{!}$/kg) were reported to contain 0.1 ng I-TEQ_{DF}/Nm^3 (2 ng I-TEQ_{DF}/kg) oil burned. The flue gases from a hot water boiler consisting of a rotary cup burner fueled with the organic phase of rinse water from oil tanks (340 mg $Cl^{!}$/kg) contained 0.2 ng I-TEQ_{DF}/Nm^3 (4.8 ng I-TEQ_{DF}/kg) oil burned. The flue gases from a steam boiler consisting of a rotary cup burner fueled by processed spent oil (240 mg $Cl^{!}$/kg) contained 0.3 ng I-TEQ_{DF}/Nm^3 (6 ng I-TEQ_{DF}/kg) oil burned. The emission factor for a ferry burning heavy fuel oil containing 11 ng/kg organic chlorine was 3.2 to 6.5 ng I-TEQ_{DF}/kg oil burned. From these data, Bremmer et al. (1994) derived an average emission factor for combustion of used oil of 4 ng I-TEQ_{DF}/kg oil burned.

Measured data from the burning of recycled waste oils are available from Austria, where emissions from a small incinerator gave a concentration of 0.02 ng TEQ/Nm (at 11% O_2) equivalent to an emission factor of 0.37 ng TEQ/kg of waste oil burned (LUA, 1997).

4.3.3.2. *Air Emission Factor*

The emission factor measured by Bremmer et al. (1994) for small combustion units was selected as most relevant to space heaters, i.e. 2 ng I-TEQ_{DF}/kg. Based on the limited data from only one study and uncertainty about how the units tested by Bremmer et al. compare to space heaters in the U.S., this is considered to be a preliminary estimate.

4.3.3.3. *Activity Level*

The total amount of waste oil burned in 1983 was 0.59 billion gallons (USEPA, 1993). Comparing this estimate with the 2006 estimate (described above) and assuming linear growth, implies that used oil combustion has increased at a rate of about 1.4% per year. The 2006 data indicates that 14.5 % of the total waste burned was in space heaters. Assuming this percentage remains constant and using the annual growth rate, allows estimates of the amount of oil burned in space heaters for each of the reference years (converted to kg based on 3.78 L/gal and density of 0.88 kg/L):

1987 – 0.30 billion kg
1995 – 0.33 billion kg
2000 – 0.35 billion kg

Based on the lack of survey data specific to the reference years and facility types, these estimates are considered preliminary.

4.3.3.4. *Air Releases*

The air releases were estimated by multiplying the emission factor and activity estimates.

4.3.3.5. *Water Releases – None*

4.3.3.6. *Solid Residue Releases – None.*

4.3.3.7. *Products – None.*

4.3.3.8. *Release Summary*

The inventory decision criteria and release estimates are summarized below:

Inventory Decision Criteria for Waste Oil Combustion				
	Air	**Water**	**Solids**	**Product**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors	No			

Inventory Decision Criteria for Waste Oil Combustion	
Measured emission factors consistent or have understandable differences	Yes
Emission factor tests represent units that are typical of the class	No
Activity estimates based on source-specific surveys	No
Conclusion (Q = Quantitative, P = Preliminary)	P

Waste Oil Combustion
Air Releases
Emission Factors • 1987 – 2 ng I-TEQ_{DF}/kg oil combusted (Preliminary) • 1995 – 2 ng I-TEQ_{DF}/kg oil combusted (Preliminary) • 2000 – 2 ng I-TEQ_{DF}/kg oil combusted (Preliminary)
Activity Levels • 1987 – 0.30 billion kg (Preliminary) • 1995 – 0.33 billion kg (Preliminary) • 2000 – 0.35 billion kg (Preliminary)
Releases • 1987 – 0.60 g I-TEQ_{DF} (Preliminary) • 1995 – 0.66 g I-TEQ_{DF} (Preliminary) • 2000 – 0.70 g I-TEQ_{DF} (Preliminary)
Water Releases
These facilities do not have wastewater releases.
Solid Residue Releases
These facilities do not have solid releases.
Products
These facilities do not have products.

4.4. COAL COMBUSTION

4.4.1. Coal-Fired Power Plants

No changes were made to the air emission factors or activity estimates, but additional background information is provided. Minor changes were made to the activity estimates for solid residues resulting in minor changes in residue amounts.

4.4.1.1. *Air Releases*

UNEP (2005) reports that Dutch data from large coal-fired power plants gave an emission factor of 0.35 μg I-TEQ/MT; German data were between 0.004 and 0.2 μg I-TEQ/MT , and U.K. data had a median value of 0.14 μg I-TEQ/MT (range: 0.06–0.32 μg I-TEQ/MT).

As discussed in EPA (2006), EPRI and DOE data were used to derive an emission factor of 0.078 ng WHO_{98} TEQ_{DF}/kg of coal combusted (0.079 ng I-TEQ_{DF}/kg). This is an average over 11 U.S. facilities, but it is on the low end of the range reported in UNEP (2005) for European facilities. Thus, there is some concern that this emission factor may be an underestimate. One reason why it may be low is because all of the tested facilities had cold-sided ESPs and experience in other industries suggested that higher emissions were likely from facilities with hot-sided ESPs. In recognition of this concern, EPA/Department of Energy (DOE) conducted testing of stack emissions in 1999 at the coal-fired Presque Island electric utility boiler in Wisconsin, which was equipped with a hot-sided ESP. The testing showed no increases in dioxin concentrations from the flue gas inlet to the outlet of a hot-sided ESP (personal communication from Thomas Feeley, National Energy Technical Laboratory, U.S. Department of Energy, Pittsburgh, PA to David Cleverly, National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington, DC on December 17, 2008). Accordingly, it is assumed that the TEQ emission factor for coal fired utilities with hot-sided ESPs is of the same order of magnitude as the average TEQ emission factors derived above.

In the year 2000, 10 facilities with an SIC code for electric services reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 63.2 g, which EPA estimates is equal to 8.9 g WHO_{98} TEQ_{DF}. No releases to other media were reported. Also, in the year 2000, two facilities with an SIC code for electric and other services combined reported dioxin releases under EPA's TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 457 g, which EPA estimates is equal to 22.2 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

The activity estimates were derived from EIA (1999b).

4.4.1.2. *Water Releases*

No data on CDD/CDF levels in water releases from these facilities were found. Because CDD/CDFs are found in the air emissions from these facilities, it is possible they could also be found in scrubber waters. Thus, water releases of CDD/CDFs from these facilities are considered possible but unquantifiable.

4.4.1.3. *Solid Residue Releases*

Dyke et al. (1997) provided data on residues from industrial coal combustion in the United Kingdom: Concentrations in fly ash were 0.23–8.7 ng TEQ/kg ash, and grate ash were 0.02–13.5 ng TEQ/kg. UNEP (2005) used these data to derive an average value of 4 ng I-TEQ/kg. A limited amount of CDD/CDF concentration data have been developed for ash from coal combustion facilities in the United States (U.S. EPA, 1999c), and these data are for wastes that are comanaged (i.e., combinations of fly ash, bottom ash, boiler slag, and flue gas desulfurization wastes). A total of 15 samples were taken from 11 disposal sites. The total mean concentration was 0.73 ng WHO_{98} TEQ_{DF}/kg (0.62 ng I-TEQ_{DF}/kg).

The total mean concentration from EPA (1999c) was selected as the only U.S. data available and within the range reported for the United Kingdom. This value of 0.73 ng WHO_9 TEQ_{DF}/kg (0.62 ng I-TEQ_{DF}/kg) was assumed to apply to all reference years.

The American Coal Ash Association (ACAA—http://www.acaa-usa.org/) releases annual production and use estimates for coal ash. Production estimates for the reference years are as follows:

- 1987—75.4 MMT
- 1995—83.6 MMT
- 2000—98.2 MMT

According to ACAA, between 25 and 30% of industrial coal ash was recycled in a variety of ways including use in cement, grout, road base materials, manufactured aggregate, fill material, snow/ice control, and agriculture. These amounts were estimated as 30% of the total ash:

- 1987—22.6 MMT
- 1995—25.1 MMT
- 2000—29.5 MMT

The potential for environmental releases from these uses is unknown, but it is assumed here that all of the CDD/CDF in the recycled ash represent an environmental release (release estimates are shown in the summary below). The emission factor presented above is based on recent testing at 11 disposal sites, but it is uncertain how much actual release occurs from these products.

The ash that was not recycled was disposed of in landfills, and these residues are not considered environmental releases. These amounts were multiplied by the ash emission factor (presented above) to get the amount landfilled (on a TEQ basis):

- 1987—38.5 g WHO_{98} TEQ_{DF} (32.7 g I-TEQ_{DF})
- 1995—42.7 g WHO_{98} TEQ_{DF} (36.3 g I-TEQ_{DF})
- 2000—50.2 g WHO_{98} TEQ_{DF} (42.6 g I-TEQ_{DF})

4.4.1.4. *Product Literature—None*

4.4.1.5. *Release Summary*

The inventory decision criteria and release estimates for all media are summarized below:

Inventory Decision Criteria for Industrial Coal-Fired Utilities	**Air**	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		Q	

Industrial Coal-Fired Utilities
Air Releases
Emission Factor • 1987—0.078 ng WHO_{98} TEQ_{DF}/kg (0.079 ng I-TEQ_{DF}/kg). • 1995—0.078 ng WHO_{98} TEQ_{DF}/kg (0.079 ng I-TEQ_{DF}/kg). • 2000—0.078 ng WHO_{98} TEQ_{DF}/kg (0.079 ng I-TEQ_{DF}/kg).
Activity Levels • 1987—651 MMT. • 1995—771 MMT. • 2000—894 MMT.
Releases • 1987—51 g WHO_{98} TEQ_{DF} (51 g I-TEQ_{DF}). • 1995—60 g WHO_{98} TEQ_{DF} (61 g I-TEQ_{DF}). • 2000—70 g WHO_{98} TEQ_{DF} (71 g I-TEQ_{DF}).
Water Releases
Because some evidence exists that wastewater from these facilities may contain CDDs and CDFs, they are classified as possible but unquantifiable (Not quantifiable) sources.
Solid Residue Releases
Emission Factor • 1987—0.73 ng WHO_{98} TEQ_{DF}/kg (0.62 ng I-TEQ_{DF}/kg) of ash. • 1995—0.73 ng WHO_{98} TEQ_{DF}/kg (0.079 ng I-TEQ_{DF}/kg) of ash. • 2000—0.73 ng WHO_{98} TEQ_{DF}/kg (0.079 ng I-TEQ_{DF}/kg) of ash.
Activity Levels • 1987—22.6 MMT ash. • 1995—25.1 MMT ash. • 2000—29.5 MMT ash.
Releases • 1987—17 g WHO_{98} TEQ_{DF} (14 g I-TEQ_{DF}). • 1995—18 g WHO_{98} TEQ_{DF} (16 g I-TEQ_{DF}). • 2000—22 g WHO_{98} TEQ_{DF} (18 g I-TEQ_{DF}).

4.4.2. Coal-Fired Industrial Boilers

4.4.2.1. *Air Releases*

No changes were made to the air emission factors, but they were upgraded from a confidence rating of preliminary to quantifiable. This was because they were based on a reasonably large study (n = 15) from the U.K. (CRE, 1994) and the likelihood that the technologies were similar to U.S. facilities. The activity estimates were updated using EIA (2006), which indicated that the amount of coal burned in industrial utilities was 68.2 MMT in 1987, 66.3 MMT in 1995, and 59.2 MMT in 2000.

4.4.2.2. *Water Literature*

No data on CDD/CDF levels in water releases from these facilities were found. Because CDD/CDFs are found in the air emissions from these facilities, it is possible they could also be found in scrubber waters. Thus, water releases of CDD/CDFs from these facilities are considered possible but unquantifiable.

4.4.2.3. *Solid Residue Releases*

No data on the CDD/CDF content of ash from industrial boilers were found; however, this should be similar to the values presented in Section 4.4.1 for coal-fired utilities. Also, the activity estimates presented for coal-fired utilities include ash from all coal combustion used to generate electricity. Thus, they should represent most of the industrial utility boilers. So it is assumed that the solid residue releases presented for the utilities include the releases from industrial boilers (see Section 4.4.1).

4.4.2.4. *Release Summary*

The inventory decision criteria and release estimates for all media are summarized below:

Inventory Decision Criteria for Industrial Coal-Fired Boilers				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Industrial Coal-Fired Boilers
Air Releases
Emission Factors • 1987—0.7 ng WHO_{98} TEQ_{DF}/kg (0.6 ng I-TEQ_{DF}/kg)of coal combusted. • 1995—0.7 ng WHO_{98} TEQ_{DF}/kg (0.6 ng I-TEQ_{DF}/kg) of coal combusted. • 2000—0.7 ng WHO_{98} TEQ_{DF}/kg (0.6 ng I-TEQ_{DF}/kg) of coal combusted.
Activity Levels • 1987—68.2 MMT. • 1995—66.3 MMT. • 2000—59.2 MMT.
Releases • 1987—48 g WHO_{98} TEQ_{DF} (41 g I-TEQ_{DF}). • 1995—46 g WHO_{98} TEQ_{DF} (40 g I-TEQ_{DF}). • 2000—41 g WHO_{98} TEQ_{DF} (36 g I-TEQ_{DF}).
Water Releases
Because some evidence exists that wastewater from these facilities may contain CDDs and CDFs, they are classified as possible but unquantifiable sources.
Solid Residue Releases
These releases are included in the estimates for coal-fired utilities presented in Section 4.4.1.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

4.4.3. Residential Coal Combustion

4.4.3.1. *Air Releases*

No changes were made to the air emission factor, but it was upgraded from preliminary to quantitative. Also a new study was found as summarized below.

Paradiz et al. (2008) measured CDD/F emissions from a coal fired domestic stove. The study was conducted in Italy using a high chlorine content coal. Testing with a non-insulated chimney yielded an emission factor of 1326 I-TEQ μg/ton of coal burned. Testing with an insulated chimney yielded an emission factor of 126 I-TEQ μg/ton of coal burned. A pronounced effect of the temperature profile in the chimney on PCDD/F emissions was identified, suggesting formation in the chimney.

As discussed in the original document, the emission factor was based on an analysis by Eduljee and Dyke (1996) on data from the Coal Research Establishment in the United Kingdom (2.1 ng I-TEQ_{DF}/kg for anthracite coal and 5.7 to 9.3 ng I-TEQ_{DF}/kg [midpoint, 7.5 ng I-TEQ_{DF}/kg] for bituminous coal). Wevers et al. (2003) measured CDD/CDF emissions from various types of household appliances used in Belgium. The average emission factor for anthracite coal burners was 77.1 ng I-TEQ/kg. UNEP (2005) reports that European studies generally show a range of 1.6 to 50 ng TEQ/kg for typical coal and emission factors as high as 660 ng I-TEQ/kg for high chlorine coals. Ultimately UNEP (2005) recommends 3 ng I-TEQ/kg for domestic burning with typical coals. Based on the similarity of the emission factor data summarized by UNEP for typical coals and estimates by Eduljee and Dyke (1996), the emission factor was upgraded from preliminary to quantitative. The congener data for emissions from normal lignite (Thub et al., 1995), indicate that the WHO_{98} TEQs were less than 9% higher than the I-TEQs. Based on this small difference, the I-TEQ emission factor was assumed to be essentially equivalent when expressed as WHO_{98} TEQs.

The activity estimates were updated using EIA (2006), which indicated that the amount of coal burned at residences was 1.6 MMT in 1987, 0.8 MMT in 1995, and 0.5 MMT in 2000. EPA (1997a) reported that 72.5% of the coal consumed by the residential sector in 1990 was bituminous and 27.5% was anthracite. These factors were assumed to apply to all reference years.

4.4.3.2. *Water Releases—None*

4.4.3.3. *Solid Residue Releases*

The solid residues from coal-fired utility boilers are likely to be similar to the solid residues from residential units. On this basis, the same emission factor is assumed to apply, i.e., 0.73 ng WHO_{98} TEQ_{DF}/kg (0.62 ng I-TEQ_{DF}/kg). UNEP (2005) suggests a “first estimate” emission factor for residues from coal fired stoves of 5,000 ng I-TEQ/kg. This is based on measurements in soot, which may not be representative of bottom ash. A preliminary confidence rating is assigned to this emission factor because it is based on testing from different facilities.

The total amount of ash generated by these facilities is assumed to be 10% of the total coal used. On this basis, the solid residues are estimated to be 0.16 MMT in 1987, 0.08 MMT in 1995, and 0.05 MMT in 2000. Some of this ash is likely to be disposed along with household trash and taken to a municipal landfill. This portion would not be considered an environmental release. Others may dispose of it on their property in a manner that is open to the environment.

4.4.3.4. ***Products—None***

4.4.3.5. ***Release Summary***

The inventory decision criteria and release estimates for all media are summarized below:

Inventory Decision Criteria for Residential Coal Combustion				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		No	
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes		No	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		P	

Residential Coal Combustion
Air Releases
Emission Factors ***Anthracite*** • 1987—2.1 ng WHO$_{98}$ TEQ$_{DF}$/kg (2.1 ng I-TEQ$_{DF}$/kg). • 1995—2.1 ng WHO$_{98}$ TEQ$_{DF}$/kg (2.1 ng I-TEQ$_{DF}$/kg). • 2000—2.1 ng WHO$_{98}$ TEQ$_{DF}$/kg (2.1 ng I-TEQ$_{DF}$/kg). ***Bituminous*** • 1987—7.5 ng WHO$_{98}$ TEQ$_{DF}$/kg (7.5 ng I-TEQ$_{DF}$/kg). • 1995—7.5 ng WHO$_{98}$ TEQ$_{DF}$/kg (7.5 ng I-TEQ$_{DF}$/kg). • 2000—7.5 ng WHO$_{98}$ TEQ$_{DF}$/kg (7.5 ng I-TEQ$_{DF}$/kg).
Activity Levels[a] • 1987—1.6 MMT. • 1995—0.8 MMT. • 2000—0.5 MMT.
Releases • 1987—10 g WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$. • 1995—5 g WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$. • 2000—3 g WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$.
Water Releases
These facilities do not have wastewater releases.
Solid Residue Releases
Emission Factors • 1987—0.73 ng WHO$_{98}$ TEQ$_{DF}$/kg (0.62 ng I-TEQ$_{DF}$/kg) (Preliminary). • 1995—0.73 ng WHO$_{98}$ TEQ$_{DF}$/kg (0.62 ng I-TEQ$_{DF}$/kg) (Preliminary). • 2000—0.73 ng WHO$_{98}$ TEQ$_{DF}$/kg (0.62 ng I-TEQ$_{DF}$/kg) (Preliminary).
Activity Levels • 1987—0.16 MMT. • 1995—0.08 MMT. • 2000—0.05 MMT.
Releases[b] • 1987—0.1 g WHO$_{98}$ TEQ$_{DF}$ (0.1 g I-TEQ$_{DF}$) (Preliminary). • 1995—0.1 g WHO$_{98}$ TEQ$_{DF}$ (0.1 g I-TEQ$_{DF}$) (Preliminary). • 2000— $<$0.1 g WHO$_{98}$ TEQ$_{DF}$ ($<$0.1 g I-TEQ$_{D}$) (Preliminary).
Products
These facilities do not have products.

[a]Note: 72.5% of the coal burned is bituminous, and 27.5% is anthracite.
[b]Note: An unknown portion of this is landfilled and, therefore, is not considered a release to the open environment.

5. COMBUSTION SOURCES OF CDDS/CDFS: OTHER HIGH-TEMPERATURE SOURCES

5.1. CEMENT KILNS

5.1.1. Air Releases

No changes were made to the air-release estimates from cement kilns. However, additional background information is provided below.

The present report uses higher emission factors for cement kilns burning hazardous waste in 1987 and 1995 than kilns not burning hazardous waste (emission factors were not needed in 2000 for hazardous waste burners because virtually all facilities had been tested). As discussed below, these higher emissions were more likely due to APCD temperatures than the hazardous waste.

World Business Council for Sustainable Development (2006) evaluated 2,200 CDD/CDF measurements made at cement kilns from the late 1970s until recently. This report concluded that coprocessing of alternative fuels and raw materials, fed to the main burner, kiln inlet or the precalciner does not influence or change the emissions of persistent organic pollutants (POPs). EPA (1999) also concluded that hazardous waste burning at cement kilns is not likely to affect emissions of dioxins/furans. Rather, these reports conclude that reducing the temperature at the inlet of the air pollution control device is one factor shown to have a significant impact on limiting dioxin formation and emissions at all types of cement kilns, independent of waste feeding. Lower APCD temperatures are believed to prevent the postcombustion catalytic formation of CDD/CDFs. This is supported by emissions testing at a Portland cement kiln which showed that CDDs/CDFs were almost entirely absent at the inlet to a hot-sided ESP, but measurements taken at the exit showed conclusively that dioxins were formed within the hot-sided ESP (U.S. EPA, 1997b). After 1995, a number of cement kilns added exhaust gas-quenching units upstream of the APCD to reduce the inlet APCD temperature, thereby reducing CDD/CDF stack concentrations.

UNEP (2005) also concluded that APCD temperature is the key factor affecting CDD/CDF emissions and recommended emission factors on this basis:

- ESP temperature <200°C—0.05 ng I-TEQ/kg of clinker
- ESP temperature 200−300°C—0.6 ng I-TEQ/kg of clinker
- ESP temperature >300°C—5 ng I-TEQ/kg of clinker

In the year 2000, nine facilities with an SIC code for "cement, hydraulic" reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The total air releases across these facilities was 201 g, which EPA estimates is equal to 36 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document, but, rather, the data are offered as supportive evidence that releases do occur.

For kilns burning hazardous waste, the emission factors were derived using test report data from 1989−1996 (U.S. EPA, 1996a). These data provided APCD inlet temperature data for 88 test runs at 14 cement kilns and allowed development of emission factors for kilns with APCD inlet temperatures greater than 232°C and for kilns with APCD inlet temperatures less than 232°C. These were used in 1987 and 1995. In 2000, almost all of the facilities had been tested, and it was unnecessary to use an emission-factor/activity-level approach to derive release estimates (U.S. EPA, 2002a).

For the kilns not burning hazardous waste, insufficient information was available to derive temperature-specific emission factors, and the same emission factor was assumed to apply to all facilities. This was derived from data in Bell (1999) and EPA (1996b) on a total of 16 facilities. The lack of temperature data for the kilns not burning hazardous waste introduces uncertainty into the emission-factor assumption and may be an underestimate if the testing did not include facilities with high-temperature control devices.

The activity data for clinker production were derived from information provided by U.S. DOC (1996) and Portland Cement Association (2001). All emission factors, activities, and release estimates are shown in the release summary below.

5.1.2. Water Releases

It is possible that the effluent from the APCD systems at these facilities contains CDDs and CDFs because they have been measured in the stack gases. No information was found on the levels in the effluent, so this is considered a possible but unquantifiable source.

5.1.3. Solid Residue Releases

No changes were made to the solid residue release estimates from cement kilns. However, additional background information is provided below.

Cement kiln dust (CKD) is the solid residual material collected by the APCD system of a cement kiln. Gross CKD (or as-generated CKD) is either recycled back into the kiln system or removed from the system for disposal (becoming net CKD or as-managed CKD). Most of the net CKD is disposed in secure landfills, but some is used for a variety of beneficial purposes such as municipal waste daily cover material, municipal waste landfill final cover material, soil stabilization for roadways or other structures, waste neutralization/stabilization/solidification (e.g., food wastes, hazardous wastes, etc.), and agricultural soil amendment. It is assumed that CDD/CDF releases could occur during the beneficial uses but not from the landfilled portions. As discussed in EPA, 2006 data on the amounts of CKD used for beneficial purposes was provided by the Portland Cement Association and split between kilns burning and not burning hazardous waste based on the relative amounts of clinker produced.

A wide range of CDD/PCDF concentrations in the CKD has been measured. A range from 0.001 to 30 ng TEQ/kg has been reported for U.K. kilns (Dyke et al., 1997), and 1−40 ng TEQ/kg were summarized for German tests (SCEP, 1994). As discussed in EPA (2006), for kilns burning hazardous waste, the CKD concentration is assumed to be 35 ng I-TEQ/kg (n = 5), and for the kilns not burning hazardous waste, the CKD concentration is assumed to be 0.003 ng I-TEQ/kg (n = 6). These emission factors were applied to all reference years. They are considered preliminary because of the inconsistency in measured values and lack of understanding for the differences. The dioxin concentrations in CKD were also used to estimate the amounts of CDD/CDFs in landfilled CKD, as shown below:

	Kilns burning hazardous waste		**Kilns not burning hazardous waste**	
	CKD activity (million kg)	**Landfilled (g I-TEQ)**	**CKD activity (million kg)**	**Landfilled (g I-TEQ)**
1987	426	14.9	2,230	0.007
1995	505	17.7	2,642	0.008
2000	365	12.8	1,858	0.006

5.1.4. Products

Clinker is the primary product of cement kilns and is ultimately used to make Portland cement. EPA (1993a) described the results of sampling and analysis of clinker conducted in 1992 and 1993. Clinker samples were collected from five cement kilns burning nonhazardous waste and six kilns burning hazardous waste. CDDs/CDFs were not detected in any of the samples. Some of the CKD is beneficially reused as discussed above. Releases associated with beneficial uses of CKD are covered under the solid residue section.

5.1.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Cement Kilns

	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		No	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		P	

Cement Kilns Not Burning Hazardous Waste
Air Releases
Emission Factor • 1987—0.27 ng WHO_{98} TEQ_{DF}/kg (0.26 ng I-TEQ/kg) of clinker produced. • 1995—0.27 ng WHO_{98} TEQ_{DF}/kg (0.26 ng I-TEQ/kg) of clinker produced. • 2000—0.27 ng WHO_{98} TEQ_{DF}/kg (0.26 ng I-TEQ/kg) of clinker produced.
Activity Levels • 1987—47.2 billion kg of clinker. • 1995—61.3 billion kg of clinker. • 2000—63.7 billion kg of clinker.
Releases • 1987—13 g WHO_{98} TEQ_{DF}/yr (12 g I-TEQ_{DF}/yr). • 1995—17 g WHO_{98} TEQ_{DF}/yr (16 g I-TEQ_{DF}/yr). • 2000—17 g WHO_{98} TEQ_{DF}/yr (17 g I-TEQ_{DF}/yr).
Water Releases
It is possible that the effluent from the APCD systems at these facilities contains CDDs and CDFs because they have been measured in the stack gases. No information was found on levels in the effluent, so this considered a possible but unquantifiable source.
Solid Residue Releases
Emission Factor • 1987—0.003 ng I-TEQ/kg (Preliminary). • 1995—0.003 ng I-TEQ/kg (Preliminary). • 2000—0.003 ng I-TEQ/kg (Preliminary).
Activity Levels • 1987—632 million kg. • 1995—547 million kg. • 2000—480 million kg.
Releases for Beneficial Uses • 1987—<0.1 g I-TEQ (Preliminary). • 1995—<0.1 g I-TEQ (Preliminary). • 2000—<0.1 g I-TEQ (Preliminary).
Products
No information was found suggesting that clinker contained measureable levels of CDDs and CDFs. Beneficial uses of CKD are covered under solid residues.

Cement Kilns Burning Hazardous Waste

Air Releases

Emission Factors

- 1987—APCD > 232°C: 31 ng WHO_{98} TEQ_{DF}/kg (29 ng I-TEQ/kg) of clinker produced.
  APCD < 232°C: 1.1 ng WHO_{98} TEQ_{DF}/kg (1.0 ng I-TEQ/kg) of clinker produced.
- 1995—APCD > 232°C: 31 ng WHO_{98} TEQ_{DF}/kg (29 ng I-TEQ/kg) of clinker produced.
  APCD < 232°C: 1.1 ng WHO_{98} TEQ_{DF}/kg (1.0 ng I-TEQ/kg) of clinker produced.
- 2000—EFs not needed because all individual facilities were tested.

Activity Levels

- 1987—APCD > 232°C: 3.8 billion kg of clinker.
  APCD < 232°C: 1 billion kg of clinker.
- 1995—APCD > 232°C: 5.04 billion kg of clinker.
  APCD < 232°C: 1.26 billion kg of clinker.
- 2000—Activity estimates not needed because all individual facilities were tested.

Releases

- 1987—APCD > 232°C: 120 g WHO_{98} TEQ_{DF}/yr (110 g I-TEQ_{DF}/yr).
  APCD < 232°C: 1 g WHO_{98} TEQ_{DF}/yr (1 g I-TEQ_{DF}/yr).
- 1995—APCD > 232°C: 160 g WHO_{98} TEQ_{DF}/yr (150 g I-TEQ_{DF}/yr).
  APCD < 232°C: 1 g WHO_{98} TEQ_{DF}/yr (1 g I-TEQ_{DF}/yr).
- 2000—19 g WHO_{98} TEQ_{DF}/yr (17 g I-TEQ_{DF}/yr).

Water Releases

It is possible that the effluent from the APCD systems at these facilities contain CDDs and CDFs because they have been measured in the stack gases. No information was found on levels in the effluent, so this considered a possible but unquantifiable source.

Solid Residue Releases

Emission Factor

- 1987—35 ng I-TEQ_{DF}/kg (Preliminary).
- 1995—35 ng I-TEQ_{DF}/kg (Preliminary).
- 2000—35 ng I-TEQ_{DF}/kg (Preliminary).

Activity Level for Beneficial Uses

- 1987—120 million kg.
- 1995—104 million kg.
- 2000—94 million kg.

Cement Kilns Burning Hazardous Waste (continued)
Releases for Beneficial Uses • 1987—4 g I-TEQ (Preliminary). • 1995—4 g I-TEQ (Preliminary). • 2000—3 g I-TEQ (Preliminary).
Products
No information was found suggesting that clinker contained measureable levels of CDDs and CDFs. Beneficial uses of CKD are covered under solid residues.

5.2. LIGHTWEIGHT AGGREGATE KILNS

5.2.1. Air Releases

No changes were made to the air-release estimates, but some clarifications are provided. Lightweight aggregate (LWA) kilns burning hazardous waste are estimated to have emitted 3.3 g I-TEQ_{DF} to air in 1990 (Federal Register, 1998) and 2.4 g I-TEQ_{DF} in 1997 (Federal Register, 1999); these estimates are used in this report for reference years 1987 and 1995, respectively. The emission factor estimate for 2000 is 1.99 ng WHO_{98} TEQ_{DF}/kg (2.06 ng I-TEQ_{DF}/kg) based on testing at 5 kilns (U.S. EPA, 2002a). As discussed in EPA, 2006, activity data were available on all 9 facilities operating in 2000 from EPA's Office of Solid Waste. This information was combined with assumptions about annual feed rates and operating time percentage to get total activity estimates. EPA (2006) mislabeled the activity estimates as applying to halogen acid furnaces rather than light weight aggregate kilns.

5.2.2. Water Releases—None

5.2.3. Solid Residue Releases—None

5.2.4. Product Literature—None

5.2.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Lightweight Aggregate Kilns				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Lightweight Aggregate Kilns
Air Releases
Emission Factors • 1987—not needed. • 1995—not needed. • 2000—2.0 ng WHO_{98} TEQ_{DF}/kg (2.1 ng I-TEQ_{DF}/kg) of waste feed.
Activity Levels • 1987—not needed. • 1995—not needed. • 2000—903,000 MT.
Releases • 1987—3 g I-TEQ_{DF}. • 1995—2 g I-TEQ_{DF}. • 2000—2 g WHO_{98} TEQ_{DF} (2 g I-TEQ_{DF}).
Water Releases
No information was found suggesting that water releases from these facilities would contain CDDs and CDFs.
Solid Residue Releases
No information was found suggesting that solid residues from these facilities would contain CDDs and CDFs.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.3. ASPHALT MIXING PLANTS

5.3.1. Air Releases

Changes were made to the air emission factor, and the releases estimated for 2000 were also assumed to apply to the reference years 1987 and 1995.

The original report estimated the emission factor on the basis of tests at two U.S. facilities. The original report also included information on testing at one facility in the Netherlands: 0.047 ng I-TEQ/kg (Bremmer et al., 1994) and three facilities in Germany: 0.0002, 0.0035, and 0.0038 ng I-TEQ/kg (Umweltbundesamt, 1996). Because the European facilities are likely similar to those in the United States, the y were averaged in with the U.S. facilities to derive an emission factor of 0.0095 ng I-TEQ/kg, and this was applied to all reference years. This factor falls within the range recommended by UNEP (2005) for asphalt mixing plants: 0.0.007 to 0.07 ng I-TEQ/kg. The confidence rating was upgraded from preliminary to quantifiable based on the additional testing used to support it and similarity to UNEP, 2005.

The original report provided an activity estimate of 500 million tons for 2000 based on 1996 survey data. Because this industry is fairly stable in terms of growth and the activity data are near the midpoint of the reference year range, it is reasonable to assume it applies to all reference years. Asphalt can be produced at both fixed and mobile facilities. It is unclear if this activity estimate includes both types of plants or only those at fixed locations. The National Cooperative Highway Research Program Web site and other related sites were searched, but no relevant information was found.

5.3.2. Water Releases

No information was found suggesting that water releases from these facilities would contain CDDs and CDFs.

5.3.3. Solid Residue Releases

UNEP (2005) indicates that flue gas cleaning residues are likely to have CDD/CDFs and suggests an emission factor of 0.06 ng I-TEQ/kg. No information was available on the quantity of this material generated. Also, it is likely that these residues would be landfilled and, therefore, not considered a release.

5.3.4. Products

No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.3.5. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Asphalt Mixing Plants				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Asphalt Mixing Plants
Air Releases
Emission Factors • 1987—0.009 ng I-TEQ/kg of asphalt produced. • 1995—0.009 ng I-TEQ/kg of asphalt produced. • 2000—0.009 ng I-TEQ/kg of asphalt produced.
Activity Levels • 1987—500 MMT. • 1995—500 MMT. • 2000—500 MMT.
Releases • 1987—5 g I-TEQ. • 1995—5 g I-TEQ. • 2000—5 g I-TEQ.
Water Releases
No information was found suggesting that water releases from these facilities would contain CDDs and CDFs.
Solid Residue Releases
Any solid residues from these facilities would be landfilled and not considered an environmental release.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.4. PETROLEUM-REFINING CATALYST REGENERATION PLANTS

5.4.1. Air Releases

No changes were made to the air-release estimates. The average of the emission factors for two California facilities (1.59 ng WHO_{98} TEQ_{DF}/barrel (1.52 ng I-TEQ_{DF}/barrel) of reformer feed) is assumed to apply to all reference years. The activity estimates were derived from EIA, 2002.

In the year 2000, one facility with an SIC code for petroleum bulk stations and terminals reported dioxin releases under EPA's TRI program (U.S. EPA, 2008). The total air releases for this facility was 102.8 g, which EPA estimates is equal to 3 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document, but, rather, the data are offered as supportive evidence that releases do occur.

5.4.2. Water Releases

As discussed in EPA (2006), CDD/CDFs have been detected in wastewaters from these facilities. However, insufficient information is available on the levels and quantities of these wastes to generate release estimates. On this basis, they are considered possible but unquantifiable sources.

5.4.3. Solid Residue Releases

As discussed in EPA (2006), CDD/CDFs have been detected in solid residues from these facilities. However, insufficient information is available on the levels and quantities of these wastes to estimate the amounts. However, these residues would be landfilled and, therefore, not considered an environmental release.

5.4.4. Product Literature

No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.4.5. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Petroleum-Refining Catalyst Regeneration Plants				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Petroleum-Refining Catalyst Regeneration Plants
Air Releases
Emission Factors • 1987—1.6 ng WHO_{98} TEQ_{DF}/barrel (1.5 ng I-TEQ_{DF}/barrel) of reformer feed. • 1995—1.6 ng WHO_{98} TEQ_{DF}/barrel (1.5 ng I-TEQ_{DF}/barrel) of reformer feed. • 2000—1.6 ng WHO_{98} TEQ_{DF}/barrel (1.5 ng I-TEQ_{DF}/barrel) of reformer feed.
Activity Levels • 1987—1,390 million barrels. • 1995—1,410 million barrels. • 2000—1,380 million barrels.
Releases • 1987—2 g WHO_{98} TEQ_{DF} (2 g I-TEQ_{DF}). • 1995—2 g WHO_{98} TEQ_{DF} (2 g I-TEQ_{DF}). • 2000—2 g WHO_{98} TEQ_{DF} (2 g I-TEQ_{DF}).
Water Releases
CDD/CDFs have been detected in wastewaters from these facilities. However, insufficient information is available on the levels and quantities of these wastes to generate release estimates. On this basis, they are considered possible but unquantifiable sources.
Solid Residue Releases
Any solid residues from these facilities would be landfilled and not considered an environmental release.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.5. CIGARETTE SMOKING

5.5.1. Air Releases

No changes were made to the air-release estimates. The air emission factor was derived using data from Matsueda et al. (1994) and Löfroth and Zebühr (1992). The activity estimates were based on Brown (2002).

5.5.2. Water Releases—None

5.5.3. Solid Residue Releases

No information was found suggesting that ash from cigarette smoking would contain CDDs and CDFs.

5.5.4. Products—None

5.5.5. Release Summary

The inventory decision criteria and releases are summarized below. Although these emission estimates are relatively small compared to many other sources, they have increased importance because humans are directly exposed to cigarette smoke.

Inventory Decision Criteria for Cigarette Smoking				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Cigarette Smoking
Air Releases
Emission Factors • 1987—1.7 pg WHO_{98} TEQ_{DF}/cigarette (1.6 pg I-TEQ_{DF}/cigarette). • 1995—1.7 pg WHO_{98} TEQ_{DF}/cigarette (1.6 pg I-TEQ_{DF}/cigarette). • 2000—1.7 pg WHO_{98} TEQ_{DF}/cigarette (1.6 pg I-TEQ_{DF}/cigarette).
Activity Levels • 1987—575 billion cigarettes. • 1995—487 billion cigarettes. • 2000—440 billion cigarettes.
Releases • 1987—1 g WHO_{98} TEQ_{DF} (0.9 g I-TEQ_{DF}). • 1995—0.8 g WHO_{98} TEQ_{DF} (0.8 g I-TEQ_{DF}). • 2000—0.7 g WHO_{98} TEQ_{DF} (0.7 g I-TEQ_{DF}).
Water Releases
None.
Solid Residue Releases
No information was found suggesting that ash from cigarette smoking would contain CDDs and CDFs.
Products
Not applicable.

5.6. PYROLYSIS OF BROMINATED FLAME RETARDANTS

The primary purpose of this report is to provide emission estimates for chlorinated dibenzo-*p*-dioxins and dibenzofurans. However, the brominated dibenzo-*p*-dioxins (BDDs) and dibenzofurans (BDFs) may also have dioxin-like toxicity. To date, though, no TEQs have been established for these compounds. Because these compounds are related to the CDDs and CDFs, some information on their emissions from facilities that pyrolyze brominated flame retardants is included in EPA (2006).

5.7. CARBON REACTIVATION FURNACES

5.7.1. Air Releases

No changes were made to the air-release estimates. The emission factor was derived from two GAC reactivation furnaces stack-tested by EPA (U.S. EPA, 1987; Lykins et al., 1987).

One test was conducted at a multiple hearth facility which is typical of large scale operations and the second test was conducted at a fluidized bed facility which is more typical of smaller operations. The activity was estimated on the basis of the mass of virgin GAC shipped each year by GAC manufacturers according to the U.S. Department of Commerce (U.S. DOC, 1990).

5.7.2. Water Releases—None

5.7.3. Solid Residue Releases—None

5.7.4. Products

No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.7.5. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Carbon Reactivation Furnaces

	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Carbon Reactivation Furnaces
Air Releases
Emission Factors • 1987—1.2 ng (WHO_{98} TEQ_{DF} or I-TEQ_{DF}) per kg of reactivated carbon. • 1995—1.2 ng (WHO_{98} TEQ_{DF} or I-TEQ_{DF}) per kg of reactivated carbon. • 2000—1.2 ng (WHO_{98} TEQ_{DF} or I-TEQ_{DF}) per kg of reactivated carbon.
Activity Levels • 1987—48,000 MT. • 1995—65,000 MT. • 2000—65,000 MT.
Releases • 1987—0.1 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 1995—0.1 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 2000—0.1 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}).
Water Releases
No water releases are produced.
Solid Residue Releases
No solid residues are produced.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.8. KRAFT BLACK LIQUOR RECOVERY BOILERS

5.8.1. Air Releases

No changes were made to the air-release estimates. The emission factor for 1987 and 1995 was based on the data for the six NCASI facilities (NCASI, 1995). For 2000, the emission factor was based on "NCASI Handbook of Chemical Specific Information for SARA Section 313 Form R Reporting." Activity estimates were derived from information provided by American Paper Institute (API, 1992), American Forest and Paper Association (AF&PA,1997), and NCASI (2002).

5.8.2. Water Releases—None

5.8.3. Solid Residue Releases

Fly ash is typically collected in ESPs at these facilities. Because CDD/CDFs have been detected in the stack gases, they are likely to be also contained in the fly ash, but no measurements have been reported. Any solid residues are likely to be landfilled and, therefore, are not considered an environmental release.

5.8.4. Products

No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.8.5. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Kraft Black Liquor Recovery Boilers				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Kraft Black Liquor Recovery Boilers
Air Releases
Emission Factors • 1987—0.03 ng WHO_{98} TEQ_{DF}/kg (0.03 ng I-TEQ_{DF}/kg) of black liquor solids. • 1995—0.03 ng WHO_{98} TEQ_{DF}/kg (0.03 ng I-TEQ_{DF}/kg) of black liquor solids. • 2000—0.010 ng WHO_{98} TEQ_{DF}/kg of black liquor solids.
Activity Levels • 1987—69.8 MMT. • 1995—80.8 MMT. • 2000—90.7 MMT for Kraft recovery furnaces.
Releases • 1987—2 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 1995—2 g (WHO_{98} TEQ_{DF} or I-TEQ_{DF}). • 2000—0.9 g WHO_{98} TEQ_{DF}/yr.
Water Releases
No water releases are produced.
Solid Residue Releases
Any solid residues from these facilities would be landfilled and not considered an environmental release.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.9. LIME KILNS

This is a new section covering lime kilns used in the pulp and paper industry as well as other industries.

5.9.1. Process Description

Lime making consists of burning of calcium and/or magnesium carbonate at a temperature between 900 and 1,500°C. The burned lime is either delivered to the end user in the form of quicklime or reacted with water in a hydrating plant to produce hydrated lime or slaked lime. Different fuels—solid, liquid, or gaseous—are used in lime burning. Most of the kilns are either shaft or rotary design and have countercurrent flow of solids and gases. Fluidized bed kilns and rotary hearths may also be found (UNEP, 2005).

5.9.2. Regulations

None specific to dioxins.

5.9.3. Air Releases

Annual emissions from lime kilns in Belgium and the United Kingdom have been reported by Wevers and De Fre (1995) and Douben et al. (1995), respectively. However, the emission factors used to generate those estimates were not provided. Umweltbundesamt (1996) reported emission factors of 0.016 to 0.028 ng I-TEQ_{DF}/kg during tests at two lime kilns in Germany.

UNEP (2005) reports that data from Europe on seven kilns, of which four were rotary kilns and three were shaft kilns, showed CDD/PCDF concentrations below 0.1 ng TEQ/Nm . Measurements at two annular shaft kilns in Germany were all below 0.05 ng I-TEQ/Nm .

High concentrations of CDD/PCDF have been measured at three kilns, two rotary kilns, and one shaft kiln, in Sweden. The measurements made between 1989 and 1993 gave concentrations between 4.1 and 42 ng N-TEQ/Nm . All measurements of high CDD/PCDF concentrations have been explained by the raw material, fuel content, or less-than-optimum burning conditions, underlining the importance of controlling the kiln inputs and maintaining a stable kiln operation (IPPC, 2001).

UNEP (2005) recommends two emission factors. For no dust controls or poor fuel, 10 μg I-TEQ/MT of CaO are recommended, and for kilns with good dust controls, 0.07 μg I-TEQ/MT of CaO are recommended.

In the year 2000, one facility with an SIC code for lime reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The total air releases for this facility was 0.73 g, which EPA estimates is equal to 0.15 g WHO_{98} TEQ_{DF}. The total land releases for this facility was 2.8 g, which EPA estimates is equal to 0.6 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

For 2000, the emission factor of 0.0058 ng WHO_{98} TEQ_{DF}/kg of CaO was used on the basis of "NCASI Handbook of Chemical Specific Information for SARA Section 313 Form R Reporting." The factors provided in this handbook were compiled from test data supplied to NCASI by a variety of sources, including NCASI member companies who had performed the tests in response to a regulatory program. Congener-specific CDD/CDF TEQ emission factors were provided (see Table 5-1).

For 2000, NCASI provided estimates of activity levels for Kraft lime kilns (Gillespie, 2002). The activity levels were reported to be 13 MMT. Insufficient information was available to make release estimates for the other reference years.

5.9.4. Water Releases

No information was found suggesting that any water releases from these facilities would contain CDDs and CDFs.

5.9.5. Solid Residue Releases

Any solid residues from these facilities would be landfilled and are not considered an environmental release.

5.9.6. Products

No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.9.7. Release Summary

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Lime Kilns				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Lime Kilns
Air Releases
Emission Factors • 1987—NA. • 1995—NA. • 2000—0.006 ng WHO_{98} TEQ_{DF}/kg of CaO.
Activity Levels • 1987—NA. • 1995—NA. • 2000—13 MMT.
Releases • 1987—NA. • 1995—NA. • 2000—0.1 g WHO_{98} TEQ_{DF}/yr.
Water Releases
No information was found suggesting that any water releases from these facilities would contain CDDs and CDFs.
Solid Residue Releases
Any solid residues from these facilities would be landfilled and are not considered an environmental release.
Products
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

5.10. GLASS MANUFACTURING

This is a new section.

UNEP (2005) provides an emission factor for glass manufacturing operations using dust abatement of 0.015 ng I-TEQ/kg of product. This factor was based on testing at three facilities in Germany. It was assumed to apply to all reference years. The amount of glass produced in the United States during 1999 was 18 MMT (DOE, 2002). Data were not found for the earlier years, and this value was assumed to apply to all of the reference years.

No information was found on CDD/CDF levels in the solid waste generated from glass manufacturing. However, these residues would be landfilled and, therefore, are not considered to be an environmental release.

The inventory decision criteria and releases are summarized below:

Inventory Decision Criteria for Glass Manufacturing				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Glass Manufacturing
Air Releases
Emission Factors • 1987—0.02 ng $I\text{-}TEQ_{DF}$/kg of metal feed. • 1995—0.02 ng $I\text{-}TEQ_{DF}$/kg of metal feed. • 2000—0.02 ng $I\text{-}TEQ_{DF}$/kg of metal feed.
Activity Levels • 1987—18 MMT. • 1995—18 MMT. • 2000—18 MMT.
Releases • 1987—0.4 g $I\text{-}TEQ_{DF}$. • 1995—0.4 g $I\text{-}TEQ_{DF}$. • 2000—0.4 g $I\text{-}TEQ_{DF}$.
Water Releases
None.
Solid Residue Releases
None.
Products
None.

5.11. OTHER IDENTIFIED SOURCES

A number of additional operations may be sources of CDD/CDF formation because the processes use chlorine-containing components or involve application of high temperatures. These include ceramics/rubber production facilities and plating/painting facilities which use thermal air-pollution control devices. Additionally automobile shredding was identified as a potential source of CDD/CDF releases. However, no testing of emissions from these processes has been performed in the United States, and only minimal emission rate information has been reported for these processes in other countries. Therefore, emissions from these sources are possible but cannot be quantified.

Miscellaneous Sources
Possible Air Releases
Ceramics and rubber manufacturers (Not quantifiable). Thermal air pollution control devices used at plating facilities and painting operations (Not quantifiable). Automobile shredders (Not quantifiable).
Possible Water Releases
Ceramics and rubber manufacturers (Not quantifiable).

Table 5-1. CDD/CDF TEQ emission factors and emission estimates from Kraft lime kilns

Congener	WHO_{98} TEQ_{DF} (ng/lb CaO)	WHO_{98} TEQ_{DF} (ng/kg CaO)
2,3,7,8-TCDD	0.00×10^{0}	0.00×10^{0}
1,2,3,7,8-PeCDD	0.00×10^{0}	0.00×10^{0}
1,2,3,4,7,8-HxCDD	0.00×10^{0}	0.00×10^{0}
1,2,3,6,7,8-HxCDD	1.00×10^{-4}	2.20×10^{-4}
1,2,3,7,8,9-HxCDD	0.00×10^{0}	0.00×10^{0}
1,2,3,4,6,7,8-HpCDD	2.80×10^{-4}	6.16×10^{-4}
1,2,3,4,6,7,8,9-OCDD	2.56×10^{-4}	5.63×10^{-4}
2,3,7,8-TCDF	8.00×10^{-4}	1.76×10^{-3}
1,2,3,7,8-PeCDF	1.00×10^{-4}	2.20×10^{-4}
2,3,4,7,8-PeCDF	0.00×10^{0}	0.00×10^{0}
1,2,3,4,7,8-HxCDF	9.00×10^{-4}	1.98×10^{-3}
1,2,3,6,7,8-HxCDF	2.00×10^{-4}	4.40×10^{-4}
1,2,3,7,8,9-HxCDF	0.00×10^{0}	0.00×10^{0}
2,3,4,6,7,8-HxCDF	0.00×10^{0}	0.00×10^{0}
1,2,3,4,6,7,8-HpCDF	0.00×10^{0}	0.00×10^{0}
1,2,3,4,7,8,9-HpCDF	0.00×10^{0}	0.00×10^{0}
1,2,3,4,6,7,8,9-OCDF	0.00×10^{0}	0.00×10^{0}
Total	2.64×10^{-3}	5.80×10^{-3}

CaO = Calcium oxide.

6. COMBUSTION SOURCES OF CDDs/CDFs MINIMALLY CONTROLLED AND UNCONTROLLED COMBUSTION SOURCES

6.1. COMBUSTION OF LANDFILL GAS

6.1.1. Air Releases

No changes were made to the air-release estimates. The emission factor was derived by averaging test results for one landfill flare in California (CARB, 1990) and one in the Netherlands (Bremmer et al., 1994). This value was assumed to apply to all reference years: 1.4 ng I-TEQ_{DF}/m^3. The emission factors for the two facilities differed by a factor of six. UNEP (2005) used studies from Germany and the U.K. to derive an emission factor of 8 µg I-TEQ/TJ of gas burned. Assuming that the landfill gas has a heating value of 16 MJ/m^3 (half that of natural gas), this converts to 0.13 ng I-TEQ/m^3. Based on the limited data and inconsistency in emission factors this was considered preliminary. As described in the 2006 document, survey data and assumptions were used to derive activity estimates.

6.1.2. Water Releases

No wet scrubbers are used for these facilities, so no releases to surface waters should occur.

6.1.3. Solid Residue Releases—None

6.1.4. Products—None

6.1.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Landfill Gas				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Combustion of Landfill Gas

Air Releases

Emission Factors

- 1987—1.4 ng $I\text{-}TEQ_{DF}/m^3$ (Preliminary).
- 1995—1.4 ng $I\text{-}TEQ_{DF}/m^3$ (Preliminary).
- 2000—1.4 ng $I\text{-}TEQ_{DF}/m^3$ (Preliminary).

Activity Levels

- 1987—1.35 billion m^3.
- 1995—4.7 billion m^3.
- 2000—16 billion m^3.

Releases

- 1987—2 g $I\text{-}TEQ_{DF}$ (Preliminary).
- 1995—7 g $I\text{-}TEQ_{DF}$ (Preliminary).
- 2000—22 g $I\text{-}TEQ_{DF}$ (Preliminary).

Water Releases

None.

Solid Residue Releases

None.

Products

None.

6.2. ACCIDENTAL FIRES

6.2.1. Structural Fires

6.2.1.1. *Air Releases*

No changes were made to the air-release estimates, but additional background information is provided below.

The most recent evidence of the release of CDD/CDFs from combustion of structures was from the collapse of the World Trade Center Towers. Pleil and Lorber (2007) examined dioxin congener concentrations and profiles from several fires including the fires that burned at Ground Zero after the collapse of the Towers for upwards of 200 days, the Binghamton office fire that occurred in the early 1980s starting from a transformer fire in the basement of the office building, and an office fire from a building in Philadelphia. The air concentrations that resulted from World Trade Center fires exceeded 100 pg WHO_{98} TEQ_{DF}/m^3 for several ambient air measurements within 500 m of the fires. The Binghamton office fire was dominated by the combustion of PCBs in the transformers. The Philadelphia office fire was typical of urban building structures. Pleil and Lorber (2007) looked at profiles of CDD/CDFs in impacted air, dust, and soot, and compared these profiles with background profiles. While their analysis did not allow for generation of an emission factor, it did produce a congener profile (see Figure 6-1).

The presence of manufactured boards and treated lumber in structures is expected to increase dioxin emissions relative to the combustion of untreated natural wood. As discussed in Section 4.2, Tame et al. (2007) reviewed the literature on the role of preservatives in the formation of dioxin in the combustion of wood. They conclude that current and emerging wood preservatives significantly increase dioxin formation during combustion in domestic stoves and in fires. Also Bhargava et al. (2002) conducted calorimeter testing and derived emission factors of 20.5 ng WHO_{98} TEQ/kg for chip boards and15.4 ng WHO_{98} TEQ/kg for medium density fiberboard (MDF) compared to nondetect to 2.5 ng WHO_{98} TEQ/kg for natural woods.

The original report (U.S. EPA, 2006) recommends an emission factor of 32 μg I-TEQ/fire based on averaging data from Carroll (1996) and Thomas and Spiro (1995). These were based on soot measurements or other indirect methods and were assigned a preliminary confidence rating. This emission factor can be converted to a mass basis by dividing by a default fuel-loading factor for structural fires of 1.15 tons/fire (ERG, 2001), yielding 28 ng I-TEQ/kg. This is much less than the emission factor of 400 ng I-TEQ/kg recommended by UNEP (2005).

No changes were made to the activity estimates which were derived from survey data in FEMA (1997, 2001) and are presented in the release summary below.

6.2.1.2. *Water Releases*

It is possible that dioxin-contaminated particles could be entrained in water used to fight fires or rainwater that falls on the site. This water could run off the site and eventually get into surface waters. No quantitative release estimates could be made.

6.2.1.3. *Solid Residue Releases*

Solid residue releases are possible because CDDs and CDFs have been measured in solid residues remaining after structural fires. EPA (2006) summarized six field studies with residue concentrations ranging from 0.03 to 130 μg I-TEQ_{DF}/kg. This wide data range is understandable considering that the amount/types of treated wood and household products found in structures is likely to be highly variable. The geometric mean of 2 μg I-TEQ_{DF}/kg of residue was selected as a central value. This was converted to an emission factor by assuming that 15% of the fuel is converted to ash (this is based on the assumption that structural fires will generate ash at a similar rate as observed for bottom ash in municipal waste combustion, which is reported by UNEP [2005] to be typically 10−20%). This yields an emission factor of 300 ng I-TEQ_{DF}/kg of material burned, which was assumed to apply to all reference years. Based on an analysis of the congener data reported by Christmann et al. (1989b) for soot from a building fire, this emission factor will be the same when converted to WHO_{98} TEQs. This value is similar to the UNEP, 2005 recommendation of 400 ng I-TEQ_{DF}/kg of material burned.

The activity estimates used to calculate residue releases for structural fires were computed by multiplying the number of fires by the default fuel-loading factor for structural fires of 1.15 tons/fire (ERG, 2001).

6.2.1.4. *Products—None*

6.2.1.5. *Release Summary*

The inventory decision criteria and releases to all media are summarized below.

The air-release estimates presented here are similar to those reached for national emission inventories developed for the Netherlands (Bremmer et al., 1994) and the United Kingdom (U.K. Department of the Environment, 1995).

Inventory Decision Criteria for Structural Fires				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No		Yes	
Measured emission factors consistent or have understandable differences.			Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	P		Q	

Structural Fires
Air Releases
Emission Factors • 1987—32 μg I-TEQ_{DF}/fire (Preliminary). • 1995—32 μg I-TEQ_{DF}/fire (Preliminary). • 2000—32 μg I-TEQ_{DF}/fire (Preliminary).
Activity Levels • 1987—746,000 fires. • 1995—574,000 fires. • 2000—512,000 fires.
Releases • 1987—24 g I-TEQ_{DF} (Preliminary). • 1995—18 g I-TEQ_{DF} (Preliminary). • 2000—16 g I-TEQ_{DF} (Preliminary).
Water Releases
Possible but unquantifiable releases.
Solid Residue Releases
Emission Factors • 1987—300 ng (WHO_{98} or I-TEQ_{DF}/kg) of material burned. • 1995—300 ng (WHO_{98} or I-TEQ_{DF}/kg) of material burned. • 2000—300 ng (WHO_{98} or I-TEQ_{DF}/kg) of material burned.
Activity Levels • 1987—860,000 tons. • 1995—660,000 tons. • 2000—589,000 tons.
Releases • 1987—260 g (WHO_{98} or I-TEQ_{DF}). • 1995—200 g (WHO_{98} or I-TEQ_{DF}). • 2000—180 g (WHO_{98} or I-TEQ_{DF}).
Products
None.

6.2.2. Vehicle Fires

6.2.2.1. *Air Releases*

No changes were made to the air-release estimates. Wichmann et al. (1993, 1995) measured CDD/CDF emissions from controlled vehicle fires in a tunnel (two cars, one subway car, and one railway car). This study suggests an emission factor of 0.044 mg I-TEQ_{DF} for cars and trucks and 2.6 mg I-TEQ_{DF}/fire for other vehicles. These values were assumed for all reference years. They are uncertain because Wichmann et al. (1993, 1995) based their estimates on surface deposits. This procedure may not have fully accounted for volatile CDDs/CDFs, which were reported by Merk et al. (1995) to account for the majority of CDDs/CDFs formed during a fire. Given the indirect method of measuring emissions, they are considered preliminary estimates. UNEP (2005) derived an emission factor of 0.094 mg I-TEQ_{DF}/incident. This was also based on Wichmann et al. (1995) and represents an average across all vehicle types.

The activity estimates were based on the number of vehicle fires reported in the United States: approximately 561,530 in 1987 (FEMA, 1997), 406,000 in 1995 (U.S. DOC, 1997), and 341,600 in 2000 (FEMA, 2001). Also, the assumption was made that 99% of those fires involved cars and trucks (the approximate percentage of all U.S. motor vehicles that are in-service cars and trucks; U.S. DOC, 1995).

6.2.2.2. *Water Releases*

It is possible that dioxin-contaminated particles could be entrained in water used to fight fires or rainwater that falls on the site. This water could run off the site and eventually get into surface waters. No quantitative release estimates could be made. Therefore, this is a possible but unquantifiable source.

6.2.2.3. *Solid Residue Releases*

The original document (US EPA, 2006) did not address solid residue releases. Solid residue releases are possible because CDDs and CDFs have been measured in solid residues remaining after vehicle fires. Wichmann et al. (1995) measured an average of 0.01 mg I-TEQ_{DF}/fire for cars and trucks and 0.8 mg I-TEQ_{DF}/fire for other vehicles. These values were adopted here for all reference years using the same data; UNEP (2005) derived a solid residues emission factor of 0.018 mg I-TEQ_{DF}/incident for all vehicles. These emission factors were combined with the same activity data reported above to estimate releases.

6.2.2.4. ***Products—None***

6.2.2.5. ***Release Summary***

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Vehicle Fires				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No		Yes	
Measured emission factors consistent or have understandable differences.			Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	P		Q	

Vehicle Fires

Air Releases

Emission Factors

Cars and Trucks

- 1987—0.044 mg I-TEQ_{DF}/incident (Preliminary).
- 1995—0.044 mg I-TEQ_{DF}/incident (Preliminary).
- 2000—0.044 mg I-TEQ_{DF}/incident (Preliminary).

Other Vehicles

- 1987—2.6 mg I-TEQ_{DF}/incident (Preliminary).
- 1995—2.6 mg I-TEQ_{DF}/incident (Preliminary).
- 2000—2.6 mg I-TEQ_{DF}/incident (Preliminary).

Activity Levels

Cars and Trucks

- 1987—556,000 vehicle fires.
- 1995—402,000 vehicle fires.
- 2000—338,000 vehicle fires.

Other Vehicles

- 1987—5,600 vehicle fires.
- 1995—4,060 vehicle fires.
- 2000—3,400 vehicle fires.

Releases

Cars and Trucks

- 1987—24 g I-TEQ_{DF} (Preliminary).
- 1995—18 g I-TEQ_{DF} (Preliminary).
- 2000—15 g I-TEQ_{DF} (Preliminary).

Other Vehicles

- 1987—15 g I-TEQ_{DF} (Preliminary).
- 1995—11 g I-TEQ_{DF} (Preliminary).
- 2000—9 g I-TEQ_{DF} (Preliminary).

All Vehicles

- 1987—39 g I-TEQ_{DF} (Preliminary).
- 1995—29 g I-TEQ_{DF} (Preliminary).
- 2000—24 g I-TEQ_{DF} (Preliminary).

Vehicle Fires (continued)
Water Releases
Possible but unquantifiable releases.
Solid Residue Releases
Emission Factors ***Cars and Trucks*** • 1987—0.01 mg I-TEQ_{DF}/incident. • 1995—0.01 mg I-TEQ_{DF}/incident. • 2000—0.01 mg I-TEQ_{DF}/incident. ***Other Vehicles*** • 1987—0.8 mg I-TEQ_{DF}/incident. • 1995—0.8 mg I-TEQ_{DF}/incident. • 2000—0.8 mg I-TEQ_{DF}/incident.
Activity Levels ***Cars and Trucks*** • 1987—556,000 vehicle fires. • 1995—402,000 vehicle fires. • 2000—338,000 vehicle fires. ***Other Vehicles*** • 1987—5,600 vehicle fires. • 1995—4,060 vehicle fires. • 2000—3,400 vehicle fires.
Releases ***Cars and Trucks*** • 1987—6 g I-TEQ_{DF}. • 1995—4 g I-TEQ_{DF}. • 2000—3 g I-TEQ_{DF}. ***Other Vehicles*** • 1987—5 g I-TEQ_{DF}. • 1995—3 g I-TEQ_{DF}. • 2000—3 g I-TEQ_{DF}. ***All Vehicles*** • 1987—11 g I-TEQ_{DF}. • 1995—7 g I-TEQ_{DF}. • 2000—6 g I-TEQ_{DF}.

6.3. LANDFILL FIRES

6.3.1. Air Releases

The original report derived a preliminary release estimate from landfill fires using a per capita release factor of 4 μg I-TEQ per person developed from Swedish data. This factor was estimated by dividing the national release estimate for Sweden by the population. This per capita approach assumes that landfill fires increase over the reference years in proportion to the population. However, improved regulations and increases in methane recovery systems at landfills are likely to have reduced landfill fire frequency/magnitude over this time frame. Accordingly, a new approach is suggested below that does not show a downward trend.

Collet and Fiani (2006) reported on the measurement of PAH, PCB, and CDD/CDF emission from simulated forest and landfill fires. For the landfill simulations, samples were collected from two landfills located in southwest France. They collected samples from what they characterized as the superficial part of the landfill ground, only the first 15 cm. These samples included municipal wastes and nonhazardous industrial wastes containing various plastics, wood, rubber, rags, and so on. The combustion chamber had an air flow of 1,800 nm^3/hour, corresponding to 22.5 volume changes per hour, to simulate open burning conditions. Emissions were sampled near the chamber exit and prior to the scrubber. They conducted two landfill fire simulations, and the emission factors for CDD/CDFs, in ng I-TEQ/kg, were 242 and 233 ng I-TEQ/kg. Collet and Fiani also provided emission factors for 12 dioxin-like PCBs, in ng I-TEQ/kg, and they were 9.9 and 16.6 ng I-TEQ/kg. Their landfill samples were collected over a surface area of 2 m^2, allowing generation of emission factors on an area basis. The emission factors for CDD/CDFs, in ng I-TEQ/m^2, were 1380 and 1321, and for the 12 dioxin-like PCBs, also in ng I-TEQ/m^2, were 56.3 and 94.2.

Persson and Bergstrom (1991) conducted experiments simulating surface and deep fires and estimated an emission factor of 1000 ng Nordic TEQ/kg of material burned for landfill fires. This value (assumed equal to 1000 ng I-TEQ/kg) was also adopted by UNEP (2005). This factor is about four times higher than the factor developed by Collet and Fiani (2006). The midpoint of this range, or 600 ng I-TEQ/kg, was adopted here for each reference year. Neither Persson and Bergstrom (1991) nor Collet and Fiani (2006) reported individual congener data that would have allowed converting this I-TEQ estimate to a WHO_{98} TEQ estimate. However, Ruokojarvi et al. (1995) reported congener profiles for air concentrations measured during a landfill fire in

Finland. This profile suggest that the WHO_{98} TEQs would be about 20% greater than the I-TEQs. On this basis, the emission factor of 600 ng I-TEQ/kg was converted to 700 ng WHO_{98} TEQ/kg. The kinds of wastes and combustion conditions occurring in landfill fires are likely to be highly variable. It is very uncertain how well these are represented in the limited experiments used to derive the emission factors. Therefore, this emission factor was assigned a preliminary confidence rating.

Blomqvist et al. (2007) used an emission factor range of 40 to 900 ng TEQ/kg for landfill fires in the Swedish inventory. This was based on two studies conducted in Sweden, one described as a "model study on household waste" and the other as one that "quantified emissions from real waste dump fires."

In order to use the per kg emission factors reported above, it is necessary to estimate the amount of waste burned in landfill fires. Persson and Bergstrom (1991) assumed that 100,000 kg of material are burned in each surface fire and 350,000 kg are burned in deep fires. The midpoint of this range (225,000 kg) was multiplied by the number of landfill fires occurring in the United States. The U.S. Fire Administration (USFA, 2001) reports that an average of 8,300 landfill fires occur each year (where landfills are defined broadly to include public or private areas where waste is buried; this includes municipal solid waste landfills and general refuse disposal areas and dumps in open ground). This suggests that a total of 1.9 MMT of material/year are burned in landfill fires in the United States. No information was found on how the number of landfill fires has changed over the reference years, and this amount (1.9 MMT) was assumed to apply to each of the years. As discussed above, the actual trend is probably downward because improved regulations and increases in methane recovery systems at landfills are likely to have reduced landfill fire frequency/magnitude over this time frame. Considering the lack of data to accurately reflect this trend and the uncertainty in the assumptions about the amount of waste burned per fire, these activity estimates are considered preliminary (Preliminary).

As shown below, this approach suggests a total release of 1,100 g I-TEQ. Another way to estimate landfill fire releases is by using a per fire emission factor. Personn and Bergstrom (1991) estimated that 35 g Nordic TEQ were released from landfills fires in Sweden. This estimate assumed that 217 fires occurred per year (167 surface fires and 50 deep fires). This implies an average release of 0.16 g Nordic TEQ/fire. Multiplying this by the number of fires occurring in the United States (8,300/year as reported by the USFA, 2001) suggests a total release of 1,300 g Nordic TEQ. This value is similar to the original one using a per capita approach, which gave estimates of about 1,000 g I-TEQ/year (assuming minor differences between Nordic TEQs and I-TEQs). Although these alternative approaches suggest similar releases, the release estimate is still considered preliminary due to the uncertainties in both the emission factor and activity estimates.

6.3.2. Water Releases—None

6.3.3. Solid Residue Releases—None

6.3.4. Products—None

6.3.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Landfill Fires				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	No			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Landfill Fires
Air Releases
Emission Factors • 1987—700 ng WHO_{98} TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary). • 1995—700 ng WHO_{98} TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary). • 2000—700 ng WHO_{98} TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary).
Activity Levels • 1987—1.9 MMT (Preliminary). • 1995—1.9 MMT (Preliminary). • 2000—1.9 MMT (Preliminary).
Releases • 1987—1,300 g WHO_{98} TEQ_{DF} (1,100 g I-TEQ_{DF}) (Preliminary). • 1995—1,300 g WHO_{98} TEQ_{DF} (1,100 g I-TEQ_{DF}) (Preliminary). • 2000—1,300 g WHO_{98} TEQ_{DF} (1,100 g I-TEQ_{DF}) (Preliminary).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

6.4. FOREST AND BRUSH FIRES

6.4.1. Air Releases

As described below, a number of additional studies have been identified, allowing updates to the air-release estimates from forest fires.

Ikeguchi and Tanaka (1999) simulated the open burning of several waste types using a large furnace with open doors. The flue gas was sampled immediately downstream of the furnace. One test was conducted with tree and leaf materials. A total of 162.7 kg of this material were burned in a batch mode lasting 33 minutes. The emission factor was estimated as 4.7 I-TEQ/kg of waste. UNEP (2005) used this study to support their recommended emission factor of 5 ng TEQ/kg of biomass burned for forest fires.

Gonczi et al. (2005) measured dioxin emissions from burning various types of domestic wastes under a variety of conditions. One test involved the open burning of garden waste, which was composed of approximately one half wood branches and one half leaves and grass. A sampling hood was mounted 0.5 m above the fire to collect the emissions. This test yielded an emission factor of 27 ng TEQ/kg.

Blomqvist et al. (2007) used an emission factor of 2 ng TEQ/kg for forest fires in the Swedish inventory. This was based on work by Bhargava et al. (2002) who measured dioxin emissions from the combustion of different wood materials in a cone calorimeter.

Collet and Fiani (2006) studied the emissions of PAHs, PCBs, and CDD/CDF emissions from simulated forest and landfill fires in France. They collected samples from two forests in the southeast and southwest of France during August, 2003. The samples consisted of litters, mosses, heathers, brackens, conifer needles, pine cones, shrubs, barks, pine, and oak branches. The 80 m^3 combustion chamber had an air flow of 1,800 m^3/hour, corresponding to 22.5 volume changes per hour, to simulate open burning conditions. Emissions were sampled near the chamber exit prior to the scrubber and measured in accordance with existing European standards (EN 1948-1-2-3 for CDD/CDFs and PCBs). For the five simulated forest fire tests, they estimated these emission factors for CDD/CDFs, in ng I-TEQ/kg: 10.4, 1.02, 25.9, 12.1, and 3.3, for an average of 10.5 ng I-TEQ/kg. Collet and Fiani also provide emission factors for 12 dioxin-like PCBs, in ng I-TEQ/kg: 0.48, 0.35, 2.34, 0.74, and 0.23, for an average of 0.8 ng I-TEQ/kg. Based on these results they provide a "first estimate" of emissions from forest fires in France of 28.8 g I-TEQ/year.

Using a controlled-burn facility, Gullett and Touati (2003) estimated CDD/CDF emissions through the testing of three biomass samples collected from the Oregon coast near Seal Rock and from four biomass samples collected from the North Carolina Piedmont region, approximately 200 km from the Atlantic coast. The samples generally consisted of equal portions of live shoots (needles cut from tree branches) and needle litter gathered from the forest floor. The Oregon samples were composed of pine needles (*Pinus contorta* and *Pinus monticola*) and hemlock needles (*Tyuga heterophylla*); the North Carolina samples were composed entirely of lobolly pine (*Pinus taeda*). The combustion of these seven samples, piled approximately 10 cm high, took place on top of an open, flat combustion platform. The average total TEQ emission factors for the three Oregon samples and the four North Carolina samples were 15 ng and 25 ng WHO_{98} TEQ_{DF}/kg, respectively. Because the waxy cuticle layer on pine needles has been demonstrated to absorb lipophilic compounds from the atmosphere, Gullett and Touati (2003) also extracted a raw, as-received Oregon biomass sample to determine whether the observed emissions were due to simple vaporization of existing CDDs/CDFs or the formation of new CDDs/CDFs in the combustion process. The CDD/CDF concentration in the sample measured 1.3 ng WHO_{98} TEQ_{DF}/kg, which is approximately 20 times lower than the Oregon CDD/CDF emission factor. The CDD/CDF isomer patterns of the extracted biomass samples and the emission samples were similar. Therefore, this preliminary evidence suggests CDD/CDF emissions are not due solely to vaporization of cuticle-bound CDDs/CDFs but are primarily a result of new formation during forest fires.

Gullett et al. (2008) present emission factor data for several types of forest and grass fires. The study used the same burn chamber as described above for Gullett and Touati (2003). Burn tests (n = 27) on forest biomass from five sources gave emission factors ranging from 0.3 to 26.3 ng TEQ/kg of carbon burned with an average of 5.8 ng TEQ/kg of carbon burned (the TEQs were reported to be essentially the same whether presented as I-TEQs or WHO_{95}). The authors indicate that forest biomass contains approximately 50% carbon. Thus, the reported emission factors can be converted to a whole biomass basis by multiplying by 0.5. The study also found that the total CDD/CDF in the emissions exceeded the amounts in the raw biomass by a factor of four, confirming that formation was occurring during the combustion process.

Meyer et al. (2004, 2007) conducted a series of chamber and field tests in Australia to characterize dioxin emission from a variety of fire types. Five chamber tests were conducted with forest leaf litter (eucalyptus, box, and ironbark) and producing a mean emission factor of 0.37 ng WHO_{98} TEQ_{DF}/kg of fuel. A total of 18 forest fire field tests were conducted using portable high volume air samplers. The field monitors also measured CO_2, which was related to combusted biomass and used to calculate emission factors. The field test results are summarized below:

- Ten prescribed burns in Queensland (coastal forest), Victoria (eucalyptus), and Western Australia (jarrah forest) with a mean emission factor of 0.5 ng WHO_{98} TEQ_{DF}/kg of fuel.
- Three fires in tropical savannas with a mean emission factor of 1.1 ng WHO_{98} TEQ_{DF}/kg of fuel.
- Two wildfires in Victoria (mixed eucalyptus) with a mean emission factor of 0.7 ng WHO_{98} TEQ_{DF}/kg of fuel.
- Three woodland fires with a mean emission factor of 1.5 ng WHO_{98} TEQ_{DF}/kg of fuel.

6.4.2. Air Emission Factors

Several lines of evidence indicate that forest fires release dioxins to the environment. Sediment core studies have shown that dioxins were found at measurable levels prior to the industrial revolution (Smith et al., 1992, 1993). The most likely source for these residues is natural fires. Gullett et al. (2003, 2008) used chamber tests to show that more dioxins are emitted than contained in the biomass being burned. Finally, multiple chamber studies and one large field study (summarized above) have now measured dioxins in forest fire emissions. Thus, it is reasonably well established that dioxin emissions occur from forest fires.

The chamber studies have shown a wide range of results (means across tests vary from 0.37 to 25 ng TEQ/kg) suggesting that emissions are highly variable across fuel types and fire conditions. The Australian field measurements suggest emission factors near the low end of the chamber results. Meyer et al. (2004) believe that the chamber tests have overestimated dioxin emissions due to longer residence time in the formation temperatures than occurs in the field. They also support their belief that forest fires have low dioxin emissions on the basis of ambient air monitoring in southern Victoria during the large forest fires in northeast Victoria in January 2003. The monitor showed clear impacts of the plume during the fire based on sharp increases in particulate and potassium salts (biomass tracer) but no increases in dioxins.

As summarized in Table 6-1, a total of 6 chamber studies have been conducted with a variety of wood types and a cumulative *n* of 46. Also, as summarized in Table 6-1, one large field study was conducted in Australia involving various types of forests with an *n* of 18. The *n*-weighted average for the field tests is 0.8 ng TEQ_{DF}/kg and for the chamber tests is 5.9 ng TEQ_{DF}/kg. As discussed below, both types of tests have uncertainties, and the midpoint of this range (3 ng TEQ_{DF}/kg) was selected as a reasonable assumption for a central value emission factor and applied to all three reference years.

The confidence in this emission factor depends on how representative the test data are of the types of wood and fires that occur in North America:

- Wood types—Over 20 different types of forests exist in the United States (see Figure 6-2) with a variety of wood types, biomass density, moisture content, height, etc. The chamber tests did not represent all wood types found in North America but did include some common types such as pine and oak. All of the field tests were conducted in

Australia; some included pines, but others were primarily eucalyptus and jarrah trees, which are uncommon in the United States.

- Fire types—A number of different types of fires can occur such as ground fires, which burn the humus layer of the forest floor but do not burn appreciably above the surface; surface fires, which burn forest undergrowth and surface litter; and crown fires, which advance through the tops of trees or shrubs. It is not uncommon for two or three of the types to occur simultaneously. The ground level monitors cannot directly sample the high smoke plume generated near the tops of trees during a crown fire. Some of the smoke generated during a crown fire is present at ground level, but it is uncertain how representative this smoke is of the main plume. Ground/surface fires create a smoke plume, which starts near ground level, and the monitors are much more likely to collect samples, which are representative of these emissions. Similarly, the chamber tests cannot mimic the intensity and scale of crown fires but may be representative of the conditions associated with the smaller ground/surface fires.

In summary, the forest fire data appear to represent some but not all of the wood types and fire types that occur in North America. The large database of emission tests suggest a wide range of emission factors, but this is reasonable considering that they cover a wide variety of wood types, fire types and burn conditions. The wide range of results increases the confidence that the full range of emission factors have been characterized and that the midpoint of the range provides a reasonable central point estimate. On this basis, the emission factor has been upgraded from preliminary to quantifiable.

6.4.3. Air Activity Levels

EPA (2006) derived forest fire activity estimates using data on acres burned per year and estimates of the amount of biomass per acre. New data for acres burned were found at a database managed by the National Interagency Fire Center (NIFC) (www.nifc.gov/fire). These new data are compared to the previously used data in Table 6-2. The data are generally comparable except for the wildfire data for 1987 and 1995 where the NIFC data are less than half the previously used values. These two estimates were changed to reflect these new data. The amount of biomass burned per acre was assumed to be 9.43 MT/acre for wildfires and 7.44 MT/acre for prescribed burns (Ward et al., 1976). The total forest fire activities were estimated as 61 MMT in 1987, 55 MMT in 1995 and 243.8 MMT in 2000. A review of the NFIC historical data on wildfires from 1960 to 2008 suggests that the acres burned in 2000 were above average and the acres burned in 1987 and 1995 were below average.

6.4.4. Water Releases

It is possible that dioxin-contaminated particles could be entrained in water used to fight fires or rainwater that falls on the site. This water could run off the site and eventually get into surface waters. No quantitative release estimates could be made. Therefore, this is a possible but unquantifiable source.

6.4.5. Solid Residue Releases

Buckland et al. (1994) collected soil samples in a national park near Sydney, Australia. Some were collected in areas where large brush fires had occurred 6 weeks earlier and others in areas where no fires had occurred. The sampling depth was 2 cm. The dioxin content of samples from burnt areas ranged from 2.2 to 36.8 pg I-TEQ/g, and the samples from unburnt areas ranged from 3.0 to 10.0 pg I-TEQ/g. They concluded that the fires had not had a major impact on the soil levels.

No other direct measures of CDD/CDF content of forest fire ash were found. Wunderli et al. (1996) determined an average of 10 ng I-TEQ/kg of ash generated for clean wood burned in stoves. This value is similar to the levels measured by Buckland et al. (1994) in surface soils after fires and is assumed here for forest fires. UNEP (2005) recommended 4 ng I-TEQ/kg of material burned (this was derived from an estimate of 200 ng I-TEQ/kg of ash and assumption of 2% ash). This emission factor is assigned a preliminary confidence rating because direct measurements were available from only one area/fire type and it is unclear if it is representative of other areas.

The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all wood burned. Multiplying this value by the activity factors discussed above for biomass burned in fires yields the following: 1.8 MMT in 1987, 1.7 MMT in 1995, and 7.3 MMT in 2000.

6.4.6. Products—None

6.4.7. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Forest and Brush Fires				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		No	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		P	

Forest and Brush Fires
Air Releases
Emission Factors • 1987—3 ng WHO$_{98}$ TEQ$_{DF}$/kg. • 1995—3 ng WHO$_{98}$ TEQ$_{DF}$/kg. • 2000—3 ng WHO$_{98}$ TEQ$_{DF}$/kg.
Activity Levels • 1987—61 MMT. • 1995—55 MMT. • 2000—243.8 MMT.
Releases • 1987—180 g WHO$_{98}$ TEQ$_{DF}$. • 1995—170 g WHO$_{98}$ TEQ$_{DF}$. • 2000—730 g WHO$_{98}$ TEQ$_{DF}$.
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—10 ng I-TEQ$_{DF}$/kg ash (Preliminary). • 1995—10 ng I-TEQ$_{DF}$/kg ash (Preliminary). • 2000—10 ng I-TEQ$_{DF}$/kg ash (Preliminary).
Activity Levels • 1987—1.8 MMT ash. • 1995—1.7 MMT ash. • 2000—7.3 MMT ash.
Releases • 1987—18 g I-TEQ$_{DF}$ (Preliminary). • 1995—17 g I-TEQ$_{DF}$ (Preliminary). • 2000—73 g I-TEQ$_{DF}$ (Preliminary).
Products
None.

6.5. BACKYARD BARREL BURNING

6.5.1. Air Releases

Additional studies are presented below, and changes were made to the 2000 activity estimate and resulting release estimate.

Hirai et al (2003) estimated total CDD/F emission factors from soil measurements at open burning sites. Soil concentrations in India of 52 pg TEQ/g implied an emission factor over 500 pg TEQ/g of waste. Soil concentrations in Cambodia of 400 pg TEQ/g implied an emission factor over 4000 pg TEQ/g of waste.

Wevers et al. (2004) measured dioxin emissions from the combustion of garden waste in barrels and in open fires, and the incineration of household waste in an empty oil drum. Each set of experiments was composed of eight individual experiments over 4 hours. Air samples were taken in the plume with a medium volume sampler equipped with a quartz filter and a polyurethane plug. Emission factors in the order of magnitude of 4.5 ng TEQ/kg combusted garden waste and 35 ng TEQ/kg burned municipal waste were determined.

Hedman et al. (2005) measured the emissions of CDD/CDFs and PCBs from uncontrolled domestic combustion of waste. The waste fuels used were garden waste, paper, paper and plastic packaging, refuse-derived fuel (RDF), PVC, and electronic scrap. Samples were collected from the emissions drawn through a conical fume hood placed directly over the barrel. Combustions including PVC and electronic scrap emitted several orders of magnitude more dioxins than the other waste fuels. Emissions from the other fuels had considerable variations, but the levels were difficult to relate to waste composition. Emission factors of CDD/CDF and PCB from the backyard burning ranged from 2.2 to 13,000 ng (WHO TEQ)/kg. The levels found in ash usually were less than 5% of the total. For assessment of total emissions of dioxins and PCB from backyard burning of low and moderately contaminated wastes, an emission factor range of 4−72 ng WHO TEQ/kg is suggested.

Gonczi et al. (2005) tested emissions from burning domestic wastes in barrels (19 tests) and open fires (2 tests). Gas collected above these fires allowed for estimation of emission factors for CDD/CDFs and dioxin-like PCBs for barrel burn and open fire conditions. The material burned consisted of various mixtures of garden wastes, straw, paper, several forms of plastic, waste motor oil, RDF, and computer scrap. A barrel burn with a mix of garden waste and polyvinyl chloride (PVC) waste had the highest emission factor of 96,000 ng WHO_{98} TEQ_{DF}/kg burned. The other emission tests ranged from 2.2 to 890 ng WHO_{98} TEQ_{P}/kg burned.

The emission factor selected in the original report was 76.8 ng WHO_{98} TEQ_{DF}/kg (72.8 ng I-TEQ_{DF}/kg) based on studies by Gullett et al. (1999, 2000) and Lemieux et al. (2000).

This falls within the range found by Gonczi et al. (2005), about twice the level found by Weveres et al. (2004) and near the upper end of the range recommended by Hedman et al. (2005). Accordingly, the original emission factor still appears to be a reasonable central estimate, and no changes were made.

The original report (US EPA, 2006) presented data from six surveys on the prevalence of backyard trash burning. This data was combined with trash generation rates and Census data on rural populations to derive national estimates of the amount of trash burned in backyards for each of the reference years. The original report also described an alternative activity estimate for 2000 developed by OAQPS. The alternative method used similar factors applied on a county by county basis and made adjustments for amount of waste recycled and influence of open burning bans. The present report considered the OAQPS method more accurate and adopted it for the year 2000. This resulted in a 16% increase in activity and a corresponding increase in releases in 2000. No changes were made to the release estimates for 1987 and 1995. All activity estimates are presented in the release summary below.

6.5.2. Solid Residue Releases

Minh et al. (2003) measured CDDs and CDFs in soils from open burning dump sites for municipal waste in the Philippines, Cambodia, India, and Vietnam. Average levels across sites ranged from 2 to 520 pg WHO_{98} TEQ/g. The levels were higher than those in agricultural and urban areas distant from the dump sites.

Lemieux (1997) collected ash samples from open barrel burning and analyzed them for CDDs/CDFs. Ash samples from the experiments were combined, resulting in two composite samples, one for recyclers, and one for nonrecyclers. The average of the recycler and nonrecycler values were averaged and assumed to apply to all three reference years: 1,670 ng WHO_{98} TEQ_{DF}/kg (1,640 ng I-TEQ_{DF}/kg) of ash.

The generation rate of ash from backyard barrel burning is assumed to match that of municipal waste incineration, which has a central estimate of 15% for bottom ash as discussed in Section 3.1. Applying this to the total amount burned (as discussed above) yields these activity levels for each reference year: 1.2 MMT in 1987, 1.2 MMT in 1990, and 1.2 MMT in 2000.

The solid residue releases were estimated by multiplying the emission factor and activity level for each reference year (results shown in summary chart below). It is possible that some of the ash from barrel burning is taken to municipal waste landfills, but most is probably not. Therefore, all of these releases are assumed to occur to the open environment.

6.5.3. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Backyard Barrel Burning				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		Q	

Backyard Barrel Burning
Air Releases
Emission Factors • 1987—77 ng WHO_{98} TEQ_{DF}/kg (73 ng I-TEQ_{DF}/kg). • 1995—77 ng WHO_{98} TEQ_{DF}/kg (73 ng I-TEQ_{DF}/kg). • 2000—77 ng WHO_{98} TEQ_{DF}/kg (73 ng I-TEQ_{DF}/kg).
Activity Levels • 1987—7.87 MMT. • 1995—8.18 MMT. • 2000—7.79 MMT.
Releases • 1987—610 g WHO_{98} TEQ_{DF} (570 g I-TEQ_{DF}). • 1995—630 g WHO_{98} TEQ_{DF} (600 g I-TEQ_{DF}). • 2000—600 g WHO_{98} TEQ_{DF} (570 g I-TEQ_{DF}).
Water Releases
None
Solid Residue Releases
Emission Factors • 1987—1,700 ng WHO_{98} TEQ_{DF}/kg (1,600 ng I-TEQ_{DF}/kg) of ash. • 1995—1,700 ng WHO_{98} TEQ_{DF}/kg (1,600 ng I-TEQ_{DF}/kg) of ash. • 2000—1,700 ng WHO_{98} TEQ_{DF}/kg (1,600 ng I-TEQ_{DF}/kg) of ash.
Activity Levels • 1987—1.2 MMT. • 1995—1.2 MMT. • 2000—1.2 MMT.
Releases • 1987—2,000 g WHO_{98} TEQ_{DF} (1,900 g I-TEQ_{DF}). • 1995—2,000 g WHO_{98} TEQ_{DF} (2,000 g I-TEQ_{DF}). • 2000—2,000 g WHO_{98} TEQ_{DF} (1,900 g I-TEQ_{DF}).
Products
None.

6.6. RESIDENTIAL YARD WASTE BURNING

Additional studies are presented below, and changes were made to the release estimates.

6.6.1. Air Releases

Ikeguchi and Tanaka (1999) simulated the open burning of several waste types using a large furnace with open doors. The flue gas was sampled immediately downstream of the furnace. One test was conducted with tree and leaf materials. A total of 162.7 kg of this material were burned in a batch mode lasting 33 minutes. The emission factor was estimated as 4.7 I-TEQ/kg of waste.

Gonczi et al. (2005) measured dioxin emissions from burning various types of domestic wastes under a variety of conditions. One test involved the open burning of garden waste, which was composed of approximately one half wood branches and one half leaves and grass. A sampling hood was mounted 0.5 m above the fire to collect the emissions. This test yielded an emission factor of 27 ng TEQ/kg.

Wevers et al. (2004) measured dioxin emissions from the combustion of garden waste in barrels and in open fires, and the incineration of household waste in an empty oil drum. Each set of experiments was composed of eight individual experiments over 4 hours. Air samples were taken in the plume with a medium volume sampler equipped with a quartz filter and a polyurethane plug. For garden waste, an emission factors of 4.5 ng TEQ/kg of waste was determined.

Hedman et al. (2005) measured the emissions of CDD/CDFs and PCBs from uncontrolled burning of various forms of household waste. Samples were collected from the emissions drawn through a conical fume hood placed directly over the barrel. For burns with garden waste (n = 3), CDD/CDF emission factors ranged from 12 to 100 ng WHO_{98} TEQ/kg of material burned with a median value of 20 ng WHO_{98} TEQ/kg of material burned.

The studies summarized above had central values ranging from about 4 to 27 ng WHO_{98} TEQ/kg of material burned. A midrange value of 10 ng WHO_{98} TEQ/kg of material burned was selected as an overall central estimate.

As described in the original report, OAQPS estimated that 255,000 MT of leaf and 255,000 MT of brush (total of 510,000 MT of yard waste) were burned in 2000. Estimates for 1987 and 1995 were derived by assuming that the activities would be proportional to the total

U.S. population for these years. This approach yields the following activity levels for each reference year: 441,000 MT in 1987, 485,000 MT in 1995, and 510,000 MT in 2000.

6.6.2. Water Releases—None

6.6.3. Solid Residue Releases

Hedman et al. (2005) measured an ash emission factor of 0.02 ng WHO_{98} TEQ/kg of waste burned for barrel burning of garden waste. It is assigned a preliminary confidence rating because it is based on only one waste sample.

6.6.4. Products—None

6.6.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Residential Yard Waste Burning				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		No	
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		P	

Residential Yard Waste Burning
Air Releases
Emission Factors • 1987—10 ng WHO_{98} TEQ_{DF}/kg. • 1995—10 ng WHO_{98} TEQ_{DF}/kg. • 2000—10 ng WHO_{98} TEQ_{DF}/kg.
Activity Levels • 1987—441,000 MT. • 1995—485,000 MT. • 2000—510,000 MT.
Releases • 1987—4 g WHO_{98} TEQ_{DF}. • 1995—5 g WHO_{98} TEQ_{DF}. • 2000—5 g WHO_{98} TEQ_{DF}.
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—0.02 ng WHO_{98} TEQ_{DF}/kg of material burned (Preliminary). • 1995—0.02 ng WHO_{98} TEQ_{DF}/kg of material burned (Preliminary). • 2000—0.02 ng WHO_{98} TEQ_{DF}/kg of material burned (Preliminary).
Activity Levels • 1987—441,000 MT. • 1995—485,000 MT. • 2000—510,000 MT.
Releases • 1987—<0.1g WHO_{98} TEQ_{DF} (Preliminary). • 1995—<0.1 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—<0.1 g WHO_{98} TEQ_{DF} (Preliminary).
Products
None.

6.7. LAND-CLEARING DEBRIS BURNING

6.7.1. Air Releases

The emission factor was changed to correspond to the new forest fire emission factor. No direct measurements of CDD/CDF emissions from the burning of land-clearing debris have been performed, so the average emission factor of 3 ng WHO_{98} TEQ_{DF}/kg, which was used for forest fires is also used for burning of land-clearing debris. This factor was assumed to apply to all three reference years. A preliminary confidence rating was assigned to the emission factor estimate because it was derived from forest fire testing and may not be representative of land-clearing debris burning.

No changes were made to the activity level estimates. As described in EPA (2006), these were provided by OAQPS and involved multiplying estimates of acres cleared during residential, nonresidential, and roadway construction by the fuel-loading factors.

6.7.2. Water Releases—None

6.7.3. Solid Residue Releases

Wunderli et al. (1996) determined an average of 10 ng I-TEQ/kg of ash generated for clean wood. This value is recommended by UNEP (2005) for virgin biomass fired stoves and is adopted here for ash from land-clearing debris burning. It is assigned a preliminary confidence rating because ash from land-clearing debris burning may be different from stove ash.

The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all debris burned. Multiplying this value by the activity factors discussed above for land clearing debris fires yields the following: 831,000 MT in 1987, 792,000 MT in 1995, and 852,000 MT in 2000.

6.7.4. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Land-Clearing Debris Burning				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No		No	
Measured emission factors consistent or have understandable differences.	No		No	
Emission factor tests represent units that are typical of the class.				
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	P		P	

Land-Clearing Debris Burning
Air Releases
Emission Factors • 1987—3 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 1995—3 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 2000—3 ng WHO_{98} TEQ_{DF}/kg (Preliminary).
Activity Levels • 1987—27.7 MMT. • 1995—26.4 MMT. • 2000—28.4 MMT.
Releases • 1987—83 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—79 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—85 g WHO_{98} TEQ_{DF} (Preliminary).
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—10 ng I-TEQ_{DF}/kg of ash (Preliminary). • 1995—10 ng I-TEQ_{DF}/kg of ash (Preliminary). • 2000—10 ng I-TEQ_{DF}/kg of ash (Preliminary).
Activity Levels • 1987—0.831 MMT ash. • 1995—0.792 MMT ash. • 2000—0.852 MMT ash.
Releases • 1987—8 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—8 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—9 g WHO_{98} TEQ_{DF} (Preliminary).
Products
None.

6.8. UNCONTROLLED COMBUSTION OF POLYCHLORINATED BIPHENYLS

No new studies were found on this topic, and no changes were made to the release estimate. The use of PCBs in new transformers in the United States is banned, and their use in existing transformers and capacitors is being phased out under regulations promulgated under the Toxic Substances Control Act.

Because of the accidental nature of these incidents, the variation in duration and intensity of elevated temperatures, the variation in CDD/CDF content of residues, and the uncertainty regarding the amount of PCBs still in service in electrical equipment, EPA judged the available data inadequate for developing any quantifiable emission estimates. Therefore, they are considered unquantifiable for air and solid residue releases. Information on this source is also presented in Chapter 11.

Uncontrolled Combustion of PCBs
CDDs and CDFs have been detected in soot from PCB fires, but the available information is insufficient to make quantitative release estimates. Therefore, it is considered an unquantifiable source for air and solid residue releases.

6.9. VOLCANOES

No evidence exists that this source can release CDDs/CDFs and, therefore, it is not even considered unquantifiable.

6.10. FIREWORKS

No new studies were found on this topic, and no changes were made to the release estimate. Evidence exists that fireworks can release CDDs/CDFs to the air and solid residues, but insufficient information exists to make a quantitative estimate. Therefore, it is considered unquantifiable for air and solid residue releases.

Fireworks
CDDs and CDFs have been detected in fireworks ash and in air after using fireworks, but the available information is insufficient to make quantitative release estimates. Therefore, it is considered an unquantifiable source for air and solid residue releases.

6.11. OPEN BURNING AND OPEN DETONATION OF ENERGETIC MATERIALS

No evidence exists that this source can release CDDs/CDFs, and, therefore, it is not even considered unquantifiable.

6.12. UNDERGROUND COAL FIRES

Underground coal fires are a possible source of CDD/CDFs to the air because CDD/CDF releases have been measured from other forms of coal burning. However, no emissions data or activity information were found specifically for this source, so no quantitative release estimate could be made (Not quantifiable).

Underground Coal Fires
The available information is insufficient to make quantitative release estimates (Not quantifiable).

6.13. AGRICULTURAL BURNING

This source category was not included in the original report. Agricultural fields are sometimes burned prior to harvesting to facilitate crop collection and sometimes after harvesting to clear the fields and control weeds. In the United States, it is believed that this practice is most prevalent for sugar cane, and it is the only crop addressed in this section.

6.13.1. Air Releases

Gullett et al. (2006) measured dioxin emission from simulated sugarcane field burns. Sugarcane leaves from Hawaii and Florida were burned in a manner simulating the natural physical dimensions and biomass density found during the practice of preharvest field burning. Eight composite burn tests consisting of 3−33 kg of biomass were conducted, some with replicate samplers. Emission factor calculations using sampled concentration and measured mass loss compared well to rigorous carbon balance methods commonly used in field sampling. The two sources of sugarcane had distinctive emission levels, as did tests on separate seasonal gatherings of the Florida sugarcane. The average emission factor for two tests of Hawaii sugarcane was 114 ng TEQ/kg of biomass and for two gatherings of Florida sugarcane was 11 ng TEQ/kg biomass and 2 ng TEQ/kg biomass (these values were originally reported on a carbon basis and were converted to a total biomass basis by multiplying by 45%).

Meyer et al. (2004) conducted a series of chamber and field tests in Australia to characterize dioxin emissions from a variety of fire types including agricultural fires. The mean emission factors from the chamber tests are listed below:

- Straw—17 ng WHO_{98} TEQ_{DF}/kg of fuel.
- Sorghum—35 ng WHO_{98} TEQ_{DF}/kg of fuel.
- Sugar cane—5 ng WHO_{98} TEQ_{DF}/kg of fuel.

Additionally, two field tests were conducted during sugar cane burning. These tests used portable high volume air samplers. The field monitors also measured CO_2, which was related to combusted biomass and used to calculate emission factors. The emission factor was 1.2 ng WHO_{98} TEQ_{DF}/kg of fuel.

UNEP (2005) recommended an emission factor for agricultural residue burning of 30 ng I-TEQ/kg of material burned (in fields where pesticides or other contaminants are present) and 0.5 ng I-TEQ/kg of material burned (in fields where pesticides or other contaminants are not present).

In summary, sugar cane chamber tests have produced a very wide range of emission factors from 2 to 114 ng TEQ/kg. The limited field testing yielded an emission factor of 1 ng TEQ/kg. Accordingly, there is considerable uncertainty about what value is most representative of U.S. conditions. For the purposes of a preliminary estimate, a value of 10 ng TEQ/kg (rounded geometric mean of range) was selected.

Gullett et al. (2006) derived activity estimates for sugar cane burning in the United States using the following factors: the sugar cane field area for Hawaii, Texas, Louisiana, and Florida; a biomass production rate of 20 dry tons/ha; and the assumption that 50% of the sugar cane crop was burned with 90% combustion efficiency. This approach suggests that about 3.5 MMT of sugar cane were burned. The data were from the 2001−2003 time frame and are assumed here to apply to 2000. USDA (2009) indicates that sugar cane production increased by about 10% from 1995 to 2000, and a similar amount is assumed for 1987 to 1995. On this basis, the amount of sugar cane burned in 1987 was 2.8 MMT, and the amount in 1995 was 3.1 MMT. Considering the multiple assumptions required for this estimate, it is assigned a preliminary confidence rating.

6.13.2. Water Releases—None

6.13.3. Solid Residue Releases

Gullett et al. (2006) measured the dioxin content of ash from several samples with a range of 0.004 to 1.22 ng WHO_{98} TEQ/kg of initial carbon of the biomass. Meyer et al. (2004) measured the dioxin content of sugar cane ash as 1 ng WHO_{98} TEQ/kg of carbon. An emission factor of 1 ng WHO_{98} TEQ/kg of carbon was selected as a central value within the range observed by Gullett et al. (2006). It was converted to 0.5 ng TEQ/kg of biomass burned assuming 45% carbon in the biomass. UNEP (2005) recommends a higher land emission factor for agricultural residue burning of 10 ng I-TEQ/kg of material burned, but the basis was not clear. Based on the limited testing showing widely ranging results, it was assigned a preliminary confidence rating.

6.13.4. Products—None

6.13.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Sugar Cane Burning				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	No		No	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	P		P	

Sugar Cane Burning
Air Releases
Emission Factors • 1987—10 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary). • 1995—10 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary). • 2000—10 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary).
Activity Levels • 1987—2.8 MMT (Preliminary). • 1995—3.1 MMT (Preliminary). • 2000—3.5 MMT (Preliminary).
Releases • 1987—28 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—31 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—35 g WHO_{98} TEQ_{DF} (Preliminary).
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—0.5 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary). • 1995—0.5 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary). • 2000—0.5 ng WHO_{98} TEQ_{DF}/kg of biomass (Preliminary).
Activity Levels • 1987—2.8 MMT (Preliminary). • 1995—3.1 MMT (Preliminary). • 2000—3.5 MMT (Preliminary).
Releases • 1987—1 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—2 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—2 g WHO_{98} TEQ_{DF} (Preliminary).
Products
None.

6.14. OPEN BURNING DEMOLITION/CONSTRUCTION WOOD

6.14.1. Air Releases

This is a new section. No direct measurements of CDD/CDF emissions from the open burning of demolition/construction wood were found. However, this activity involves similar material as burned in structural fires. As discussed in Section 6.2.1, the presence of manufactured boards and treated lumber in structures is expected to increase dioxin emissions relative to the combustion of untreated natural wood. Section 6.2.1 derived a structural fire emission factor of 32 μg I-TEQ/fire by averaging data from Carroll (1996) and Thomas and Spiro (1995) and converting to a mass basis by dividing by a default fuel-loading factor for structural fires of 1.15 tons/fire (ERG, 2001), yielding 28 ng I-TEQ/kg. This factor was assumed to apply to the open burning of demolition/construction wood for all three reference years. A preliminary confidence rating was assigned to the emission factor estimate because it was derived from structural fire estimates that were considered preliminary.

U.S. DOE (2000) reports that 8 MMT of wood construction and demolition debris were generated in 1995. The majority of this waste was legally disposed via landfill or incineration. However, an unknown portion is open burned at construction sites. For the purposes of a preliminary estimate, it is assumed that 10% of the total, or 0.8 MMT, is open burned during all three reference years.

6.14.2. Water Releases—None

6.14.3. Solid Residue Releases

As discussed in Section 6.2, an ash emission factor of 300 ng WHO_{98} TEQ_{DF}/kg of material burned was developed for structural fires and is adopted here for ash from open burning of construction/demolition wood. A preliminary confidence rating was assigned to the emission factor estimate because it was derived from structural fire estimates.

The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all wood burned. Multiplying this value by the activity factors discussed above for open burning of construction/demolition wood yields the following: 0.024 MMT in all reference years. These are given a preliminary confidence rating because they are derived from emission factors with preliminary confidence ratings.

6.14.4. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Open Burning Demolition/Construction Wood				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No		No	
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	No		No	
Activity estimates based on source-specific surveys.	No		No	
Conclusion (Q = Quantitative, P = Preliminary).	P		P	

Open Burning Demolition/Construction Wood
Air Releases
Emission Factors • 1987—28 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 1995—28 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 2000—28 ng WHO_{98} TEQ_{DF}/kg (Preliminary).
Activity Levels • 1987—0.8 MMT (Preliminary). • 1995—0.8 MMT (Preliminary). • 2000—0.8 MMT (Preliminary).
Releases • 1987—22 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—22 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—22 g WHO_{98} TEQ_{DF} (Preliminary).
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—300 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 1995—300 ng WHO_{98} TEQ_{DF}/kg (Preliminary). • 2000—300 ng WHO_{98} TEQ_{DF}/kg (Preliminary).
Activity Levels • 1987—0.024 MMT (Preliminary). • 1995—0.024 MMT (Preliminary). • 2000—0.024 MMT (Preliminary).
Releases • 1987—7 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—7 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—7 g WHO_{98} TEQ_{DF} (Preliminary).
Products
None.

6.15. OIL SPILL BURNING

Aurell and Gullett (2010) measured dioxin emissions during *in situ* burning of oil spilled into the Gulf of Mexico over the time period of July 13-16, 2010. They derived an emission factor of 1.7 ng TEQ/kg of oil burned assuming that congeners below detection limits equal zero.

If congeners below detection limits were set to their full detection limit, the emission factor was estimated to be 3.0 ng TEQ/kg. However, no activity information was found specifically for *in situ* oil burning during the reference years, so no quantitative release estimate could be made (Not quantifiable).

Oil Spill Burning
The available information is insufficient to make quantitative release estimates (Not quantifiable).

6.16. CANDLE BURNING

Candle burning is a possible source of CDD/CDFs to the air because CDD/CDF releases have been measured from other types of fires. However, no emissions data or activity information were found specifically for this source, so no quantitative release estimate could be made (Not quantifiable).

Candle Burning
The available information is insufficient to make quantitative release estimates (Not quantifiable).

Table 6-1. CDD/CDF emission factors (ng/kg) for forest fires

Biomass description and location	Wood type	Test device	*n*	ng TEQ_{DF}/kg of biomass Mean (Range)	Reference
Tree from Central North Carolina	Loblolly pine	Chamber	7	0.86[a]	Gullett et al. (2008)
Pile—Central North Carolina	Loblolly pine	Chamber	10	0.615[a]	Gullett et al. (2008)
Supplement—Central North Carolina	Loblolly pine	Chamber	2	0.93[a]	Gullett et al. (2008)
Supplement—Western North Carolina	White pine	Chamber	2	1.225[a]	Gullett et al. (2008)
Supplement—Oregon	Hemlock/Pine	Chamber	2	1.64[a]	Gullett et al. (2008)
Shrub—California	Titi, pine straw, gallberry	Chamber	2	8.36[a]	Gullett et al. (2008)
Shrub—Florida	Maritime chaparral	Chamber	2	2.62[a]	Gullett et al. (2008)
Central North Carolina	White pine	Chamber	4	25 (14−47)	Gullett and Touati (2003)
Oregon	Hemlock/Pine	Chamber	3	15 (1−56)	Gullett and Touati (2003)
Tree and leaves from Japan	Unspecified	Chamber	1	4.7	Ikeguchi and Tanaka (1999)
Wood, leaves, and grass from Sweden	Unspecified	Hood over fire on plate	1	27	Gonczi et al. (2005)

Table 6-1. CDD/CDF emission factors (ng/kg) for forest fires (continued)

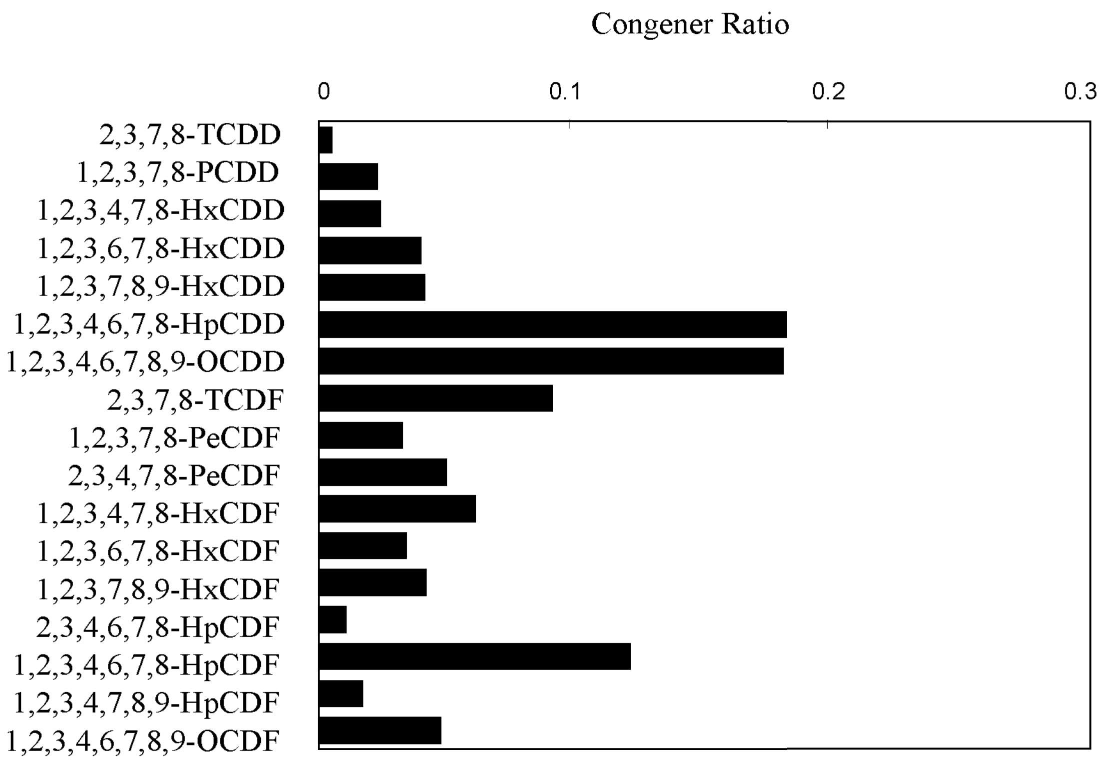
Biomass description and location	Wood type	Test device	*n*	ng TEQ_{DF}/kg of biomass Mean (Range)	Reference
Litters, mosses, heathers, brackens, conifer needles, pine cones, shrubs, barks, and branches from France	Pine and oak	Chamber	5	10 (1−26)	Collet and Fiani (2006)
Forest leaf litter from three locations in Australia	Eucalyptus, box, ironback	Chamber	5	0.37 (0.09−0.79)	Meyer et al. (2004)
Prescribed forest fires in Queensland, Victoria, and Western Australia	Eucalyptus	Field	10	0.5 (0.07−1.4)[a]	Meyer et al. (2004, 2007)
Tropical savanna—Australia	Unspecified	Field	3	1.1 (0.2−2.8)[a]	Meyer et al. (2004, 2007)
Wildfires in Victoria	Eucalyptus	Field	2	0.7 (0.6−0.8)[a]	Meyer et al. (2004, 2007)
Woodlands in Australia	Unspecified	Field	3	1.5 (0.9−2.5)[a]	Meyer et al. (2004, 2007)

[a]Originally reported as ng TEQ/kg of carbon and converted to ng TEQ/kg of biomass by multiplying by 0.5.

Table 6-2. Comparison of Forest Fire Data (million acres burned/year)

Fire type and year	CEQ, 1997	U.S. EPA, 2002d	NIFC, 2009
Wildfires—1987	5		2.45
Wildfires—1995	7		1.84
Wildfires—2000		8.36	7.39
Prescribed Fires—1987	5.1		NA
Prescribed Fires—1995	5.1		NA
Prescribed Fires—2000		1.26	1.19

NA= Not Available.



Source: Pleil and Lorber (2007)

Figure 6-1. Congener profile for structure fires.

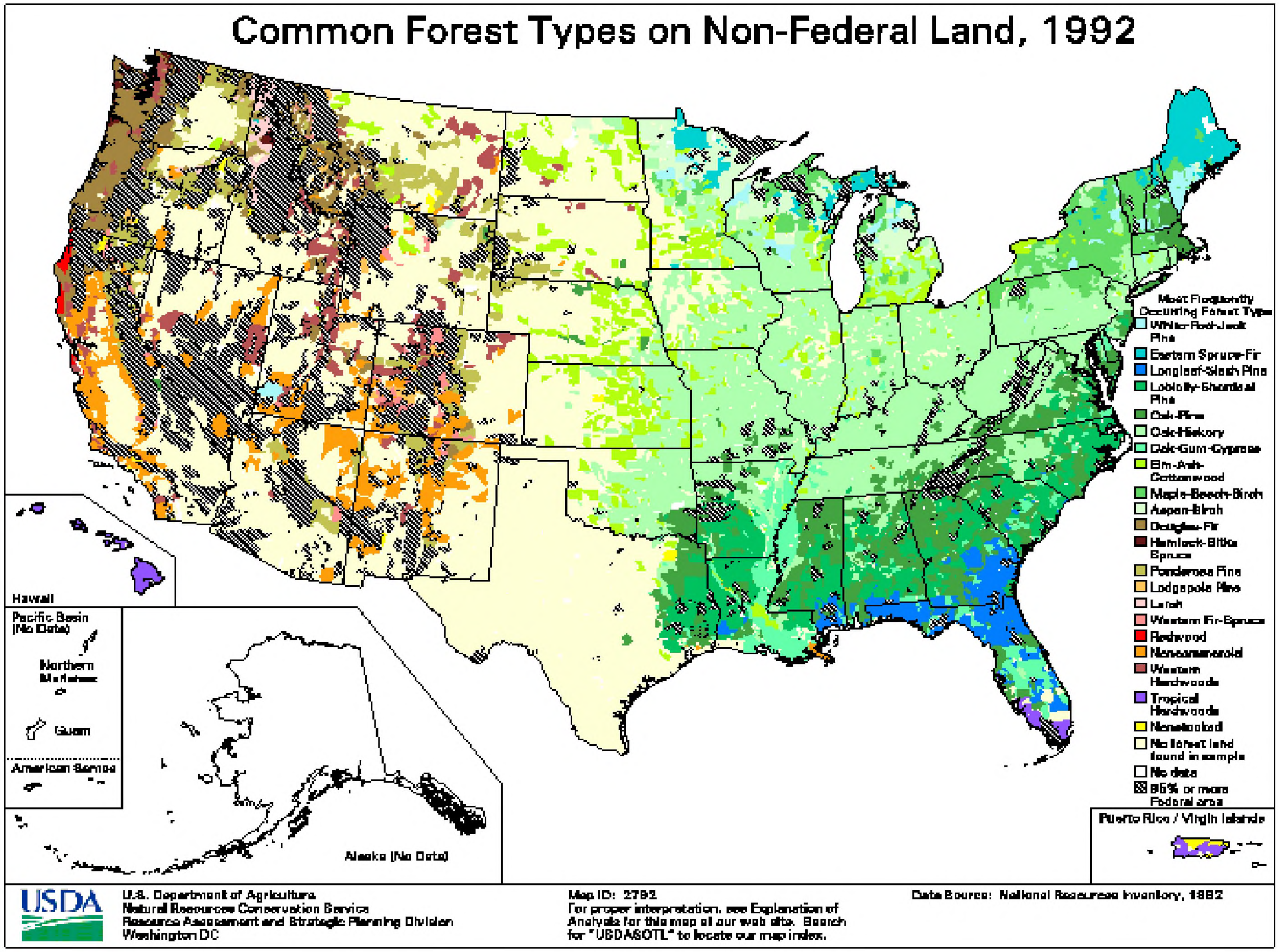


Figure 6-2. Forest fire types in the United States.

7. METAL SMELTING AND REFINING SOURCES OF CDD/CDFS

This chapter addresses dioxin releases associated with primary and secondary metal processing. Primary processes involve the extraction of the base metal from mineral ores. Secondary processes extract the base metal from recycled or waste materials.

7.1. PRIMARY NONFERROUS METAL SMELTING/REFINING

7.1.1. Primary Copper Smelting and Refining

Minor changes were made to the air-release estimates.

7.1.1.1. *Air Releases*

The emission factor was derived from testing at two facilities by Environmental Risk Sciences, Inc. (1995), who used stack testing results to calculate the annual TEQ emission to air to be less than 0.5 g I-TEQ_{DF} in 1995 for the seven facilities (out of a total of eight) belonging to the National Mining Association. Using the activity level presented below of 1.60 MMT for 1995, the emission factor is calculated to be 0.31 ng I-TEQ_{DF}/kg of copper. This emission factor was applied to all three reference years.

In 1987, copper refineries produced 1.13 MMT of copper (USGS, 1997a). In 1995, eight primary copper smelters were in operation in the United States; one of which closed at the end of that year (Edelstein, 1995). Total refinery production was 1.60 MMT in 1995, including 0.36 MMT from scrap material (Edelstein, 1995). In 2000, four primary smelters of copper were in operation in the United States, producing 1.61 MMT of copper (USGS, 2002a).

7.1.1.2. *Water Releases*

No information was found on water releases from these facilities.

7.1.1.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.1.1.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.1.1.5. *Release Summary*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Primary Copper Smelting and Refining				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Primary Copper Smelting and Refining
Air Releases
Emission Factors • 1987—0.31 ng I-TEQ_{DF}/kg of copper. • 1995—0.31 ng I-TEQ_{DF}/kg of copper. • 2000—0.31 ng I-TEQ_{DF}/kg of copper.
Activity Levels • 1987—1.13 MMT of copper. • 1995—1.60 MMT of copper. • 2000—1.61 MMT of copper.
Releases • 1987—0.3 g I-TEQ. • 1995—0.5 g I-TEQ. • 2000—0.5 g I-TEQ.
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.1.2. Primary Magnesium Smelting and Refining

7.1.2.1. *Air Releases*

No change was made to the emission factor, but minor changes were made to the activity estimates and resulting release estimates. The emission factor was derived from stack testing at a Utah facility (Western Environmental Services and Testing, Inc., 2000). This was originally reported as 105 ng I-TEQ/kg of magnesium produced and is converted here to 94 ng WHO_{98} TEQ/kg of magnesium produced based on congener data presented in Western Environmental Services and Testing, Inc., 2000. Even though the testing occurred at only one facility, the estimated releases for the year 2000 are included in the quantitative inventory. This is because the Utah facility was the only one operating in the United States in 2000. Additional facilities were operating in 1987 and 1995 and it is uncertain how well the testing at the Utah facility represented the others. Therefore, the release estimates for 1987 and 1995 were considered preliminary. The activity estimates were derived from production data from the U.S. Geological Society (USGS, 2002).

Under the EPA TRI program for 2000, this facility reported air releases of 623 g CDD/CDFs (3.3 g WHO_{98} TEQ_{DF}) and on-site surface impoundments of 1,661 g CDD/CDFs (8.3 g WHO_{98} TEQ_{DF}) (U.S. EPA, 2008). No releases to other media were reported. As explained in Chapter 1, the accuracy of the TRI data is unknown, and, therefore, they are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

7.1.2.2. *Water Releases*

Monitoring of wastewater discharges from U.S. magnesium production facilities for CDD/CDF content has not been reported. Wastewater discharges of CDDs/CDFs reported for the Norwegian facility (Oehme et al., 1989) are not adequate to support development of wastewater emission factors for U.S. facilities because of possible differences in the processes used to manufacture $MgCl_2$ and pollution control equipment. Therefore, water releases are possible but could not be quantified.

7.1.2.3. *Solid Residue Releases*

CDD/CDFs have been reported in waste sludge generated during magnesium production. EPA (2008) reports that in the year 2001, Magnesium Corporation of America (Rowley, UT) released 2,289 g total CDD/CDF (10 g WHO_{98} TEQ_{DF}, or 12 g I-TEQ_{DF}) to on-site surface impoundments. The potential for environmental release is unknown (Not quantifiable).

7.1.2.4. *Release Summary*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Primary Magnesium Smelting and Refining				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P/Q[a]			

[a]Preliminary for 1987 and 1995, Quantitative for 2000 because testing occurred at only facility operating in 2000.

Primary Magnesium Smelting and Refining
Air Releases
Emission Factors • 1987—94 ng WHO_{98} TEQ_{DF}/kg (110 ng I-TEQ_{DF}/kg). (Preliminary) • 1995—94 ng WHO_{98} TEQ_{DF}/kg (110 ng I-TEQ_{DF}/kg). (Preliminary) • 2000—94 ng WHO_{98} TEQ_{DF}/kg (110 ng I-TEQ_{DF}/kg).
Activity Levels • 1987—0.142 MMT. • 1995—0.142 MMT. • 2000—0.083 MMT.
Releases • 1987—13 g WHO_{98} TEQ_{DF} (16 g I-TEQ_{DF}). (Preliminary) • 1995—13 g WHO_{98} TEQ_{DF} (16 g I-TEQ_{DF}). (Preliminary) • 2000—8 g WHO_{98} TEQ_{DF} (9 g I-TEQ_{DF}).
Water Releases
Releases are possible but could not be quantified.
Solid Residue Releases
Releases are possible but could not be quantified.
Products
None.

7.1.3. Primary Nickel Smelting and Refining

No changes were made in the release estimates from these facilities.

7.1.3.1. *Air Releases*

The emissions information contained in the Norwegian study (Oehme et al., 1989) is not adequate to support development of emission factors for the U.S. facility for 1987 and 1995. Since the only U.S. facility closed in 1998, emissions for 2000 are zero.

7.1.3.2. *Water Releases*

EPA (2006) reports that one study (Oehme et al., 1989) measured CDD/CDFs in wastewater releases from a nickel production plant in Norway. The information is not adequate to support development of emission factors for the United States. Thus, releases are possible but could not be quantified in 1987 and 1995. Since the only U.S. facility closed in 1998, emissions for 2000 are zero.

7.1.3.3. *Solid Residue Releases*

No information was found indicating that CDD/CDFs were present in solid residues from these facilities.

7.1.3.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.1.3.5. *Release Summary*

The release estimates are summarized below:

Primary Nickel Smelting and Refining
Air Releases
Releases are possible but could not be quantified in 1987 and 1995 and were zero in 2000.
Water Releases
Releases are possible but could not be quantified in 1987 and 1995 and were zero in 2000.
Solid Residue Releases
None.
Products
None.

7.1.4. Primary Aluminum Smelting and Refining

No changes were made to the release estimates for these facilities, but additional background information is provided below.

The use of hexachloroethane during aluminum production has been identified as a cause for dioxin emissions (UNEP, 2005). The production of hexachloroethane ceased in the United States in the 1970s, so it is not likely to have been used for this purpose during the reference years (ATSDR, 1997). UNEP (2005) did not determine emission factors for primary aluminum production.

Kucherenko et al. (2001) measured CDD/CDFs emissions from a primary aluminum plant in Krasnoyarsk, Russia. The air release emission factor was estimated as 11 ng I-TEQ/kg, and the water release emission factor was estimated as 0.141 ng I-TEQ/L. It is unknown how similar this plant is to those in the United States.

In summary, insufficient information is available to estimate if CDD/CDF releases occur from these facilities in the United States.

7.1.5. Primary Titanium Smelting and Refining

No changes were made to the release estimates from these facilities, but additional background information is provided below.

In the year 2000, nine facilities with an SIC code for inorganic pigments reported dioxin releases under EPA's TRI program. The air and water releases summed across these facilities were less than 1 g WHO_{98} TEQ_{DF}. A total of 240 g WHO_{98} TEQ_{DF} were disposed in landfills (U.S. EPA, 2008). No releases to other media were reported. As explained in Chapter 1, the accuracy of the TRI data is unknown, and therefore, they are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

7.1.5.1. *Air Releases*

Based on the TRI data reported above, air releases are possible but could not be quantified.

7.1.5.2. *Water Releases*

Based on the TRI data reported above, water releases are possible but could not be quantified.

7.1.5.3. *Solid Residue Releases*

Titanium dioxide production creates a variety of sludge wastes, which can contain CDDs/CDFs. As discussed above, the TRI data suggest that inorganic pigment facilities disposed a total of 240 g WHO_{98} TEQ_{DF} in landfills in 2000 (U.S. EPA, 2008).

EPA (2001) reports the following measurements in wastes generated in conjunction with chlorinators:

- Millennium Baltimore, chloride solids/waste acid: 812 ng WHO_{98} TEQ_{DF}/L.
- Millennium Baltimore, filter press solids: 2,615 ng WHO_{98} TEQ_{DF}/kg.
- DuPont Edge Moor, iron rich: 58.7 ng WHO_{98} TEQ_{DF}/kg.
- DuPont New Johnsonville, wastewater treatment solids: 402 ng WHO_{98} TEQ_{DF}/kg.

EPA (2001) reports that the production of wastewater treatment sludges from comingled chloride and sulfate process wastewaters at the Millennium Plant was 93,121 MT/year. Combining this production rate with an assumed 1,000 ng WHO_{98} TEQ_{DF}/kg suggests that about 90 g WHO_{98} TEQ_{DF}/year may be associated with these sludges at this plant.

For the most part, these sludges have been disposed of in either on-site or off-site RCRA Subtitle D solid waste disposal facilities. However, given the potential for leaching of the heavy metals from the sludge in the Subtitle D landfill, EPA has listed this waste as hazardous waste under Subtitle C. These sludges are now considered a hazardous waste under RCRA and must be disposed of in permitted landfills (U.S. EPA, 2001). These amounts are not considered to cause environmental releases under the definition in this document.

7.1.5.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.1.5.5. *Release Summary*

The release estimates are summarized below:

Primary Titanium Smelting and Refining
Air Releases
Not quantifiable.
Water Releases
Not quantifiable.
Solid Residue Releases
None.
Products
None.

7.2. SECONDARY NONFERROUS METAL SMELTING AND REFINING

7.2.1. Secondary Aluminum Smelting and Refining

No changes were made in the release estimates from these facilities, but some additional background information is provided below.

7.2.1.1. *Air Releases*

The emission factors were derived from testing at seven facilities (CARB, 1992a, b; U.S. EPA, 1995c). Activity data were based on survey information from USGS (2002a).

In the year 2000, 29 facilities with an SIC code for secondary smelting and refining of nonferrous metals reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). Most of these facilities appeared to be aluminum producers. The sum of the air releases across these facilities was 1,022 g, which EPA estimates is equal to 13.8 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

7.2.1.2. *Water Releases*

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.2.1.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.2.1.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.2.1.5. *Releases*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Secondary Aluminum Smelting and Refining				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Secondary Aluminum Smelting and Refining
Air Releases
Emission Factors • 1987—15 ng WHO$_{98}$ TEQ$_{DF}$/kg (14 ng I-TEQ$_{DF}$/kg). • 1995—15 ng WHO$_{98}$ TEQ$_{DF}$/kg (14 ng I-TEQ$_{DF}$/kg). • 2000—5.2 ng WHO$_{98}$ TEQ$_{DF}$/kg (4.9 ng I-TEQ$_{DF}$/kg).
Activity Levels • 1987—0.7 MMT. • 1995—1.3 MMT. • 2000—1.6 MMT.
Releases • 1987—11 g WHO$_{98}$ TEQ$_{DF}$(10 g I-TEQ$_{DF}$). • 1995—20 g WHO$_{98}$ TEQ$_{DF}$(18 g I-TEQ$_{DF}$). • 2000—8 g WHO$_{98}$ TEQ$_{DF}$(8 g I-TEQ$_{DF}$).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.2.2. Secondary Copper Smelting and Refining

No changes were made in the release estimates from these facilities.

7.2.2.1. *Air Releases*

Only three facilities were active during the reference years. The emission factors were derived from stack testing at these plants as described in US EPA (2006). The release summary below shows the emission factor and activity estimates (based on data for each plant) in each reference year.

7.2.2.2. *Water Releases*

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.2.2.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.2.2.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.2.2.5. *Releases*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Secondary Copper Smelting and Refining				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Secondary Copper Smelting and Refining
Air Releases
Emission Factors ***Franklin*** • 1987—17,000 ng WHO_{98} TEQ_{DF}/kg (17,000 ng I-TEQ_{DF}/kg). • 1995—17.000 ng WHO_{98} TEQ_{DF}/kg (17,000 ng I-TEQ_{DF}/kg). ***Chemetco*** • 1987—3.7 ng WHO_{98} TEQ_{DF}/kg (3.6 ng I-TEQ_{DF}/kg). • 1995—3.7 ng WHO_{98} TEQ_{DF}/kg (3.6 ng I-TEQ_{DF}/kg). • 2000—3.7 ng WHO_{98} TEQ_{DF}/kg (3.66 ng I-TEQ_{DF}/kg). ***Gaston*** • 1987—8,900 ng WHO_{98} TEQ_{DF}/kg (8,700 ng I-TEQ_{DF}/kg).
Activity Levels ***Franklin*** • 1987—13,600,000 kg. • 1995—16,000,000 kg. ***Chemetco*** • 1987—120,000,000 kg. • 1995—135,000,000 kg. • 2000—235,000,000 kg. ***Gaston*** • 1987—85,000,000 kg.
Releases • 1987—990 g WHO_{98} TEQ_{DF} (970 g I-TEQ_{DF}). • 1995—270 g WHO_{98} TEQ_{DF} (270 g I-TEQ_{DF}). • 2000—0.9 g WHO_{98} TEQ_{DF} (0.8 g I-TEQ_{DF}).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.2.3. Secondary Lead Smelting

No changes were made in the release estimates from these facilities.

7.2.3.1. *Air Releases*

Three types of furnaces are used in secondary lead smelting. CDD/CDF emission factors were estimated for secondary lead smelters using the results of emission tests performed by EPA at three smelters (a blast furnace [U.S. EPA, 1995b], a colocated blast/reverberatory furnace [U.S. EPA, 1992a], and a rotary kiln furnace [U.S. EPA, 1995c]). Activity estimates were derived from USGS survey data. The release summary below shows the emission factor and activity for each furnace type in each reference year.

7.2.3.2. *Water Releases*

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.2.3.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.2.3.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.2.3.5. *Releases*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Secondary Lead Smelting				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Secondary Lead Smelting

Air Releases

Emission Factors

Blast furnaces without scrubber

- 1987, 1995, 2000— 8.8 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (8.3 ng I-$\mathrm{TEQ_{DF}}$/kg).

Blast furnaces with scrubber

- 1987, 1995, 2000—0.64 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (0.63 ng I-$\mathrm{TEQ_{DF}}$/kg).

Reverberatory and colocated furnaces without scrubber

- 1987, 1995, 2000—0.42 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (0.41 ng I-$\mathrm{TEQ_{DF}}$/kg).

Reverberatory and colocated furnaces with scrubber

- 1987, 1995, 2000—0.05 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (0.05 ng I-$\mathrm{TEQ_{DF}}$/kg).).

Rotary furnaces without scrubber

- 1987, 1995, 2000—0.66 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (0.66 ng I-$\mathrm{TEQ_{DF}}$/kg).

Rotary furnaces with scrubber

- 1987, 1995, 2000—0.24 ng $\mathrm{WHO_{98}\ TEQ_{DF}}$/kg (0.24 ng I-$\mathrm{TEQ_{DF}}$/kg).

Activity Levels

Blast furnaces (14% with and 86% without scrubbers)

- 1987—0.15 MMT.
- 1995—0.2 MMT.
- 2000—0.29 MMT.

Reverberatory and colocated furnaces (52% with and 48% without scrubbers)

- 1987—0.53 MMT.
- 1995—0.72 MMT.
- 2000—1 MMT.

Rotary furnaces (57% with and 43% without scrubbers)

- 1987—0.04 MMT.
- 1995—0.05 MMT.
- 2000—0.07 MMT.

Releases

- 1987—1 g $\mathrm{WHO_{98}\ TEQ_{DF}}$ (1 g I-$\mathrm{TEQ_{DF}}$).
- 1995— 2 g $\mathrm{WHO_{98}\ TEQ_{DF}}$ (2 g I-$\mathrm{TEQ_{DF}}$).
- 2000—2 g $\mathrm{WHO_{98}\ TEQ_{DF}}$ (2 g I-$\mathrm{TEQ_{DF}}$).

Water Releases

None.

Solid Residue Releases

None.

Products

None.

7.2.4. Secondary Zinc Production

This is a new section.

More than one-fourth of the total zinc (Zn) consumed in 2002 by domestic industries was secondary Zn. About 87% of recycled zinc was derived from new scrap, generated mainly in galvanizing and die casting plants and brass mills. The remaining 13% was obtained from brass products, flue dust, old die casts, and old rolled Zn articles. Recycled Zn was used by 2 primary smelters and 13 large and medium (more than 1,000 tons/year) sized secondary smelters principally for production of zinc chemicals, mainly oxide, and Zn metal, including alloys (USGS, 2002b).

Clean new scrap, mainly brass, rolled zinc clippings, and rejected die castings, usually requires only remelting. In the case of mixed nonferrous shredded metal scrap, zinc is separated from other materials by hand or magnetic separation. Most of the zinc recovered from dust produced during remelting of galvanized steel scrap, is recovered in rotary kilns by using the Waelz process (USGS, 2009a).

7.2.4.1. *Air Releases*

UNEP (2005) proposed several zinc related emission factors based on testing at facilities in Germany and Japan:

- Kilns with no APCs—1,000 ng I-TEQ/kg of zinc
- Hot briquetting/rotary furnaces with basic dust controls—100 ng I-TEQ/kg of zinc
- Furnaces with comprehensive pollution controls—5 ng I-TEQ/kg of zinc
- Zinc melting—0.3 ng I-TEQ/kg of zinc

The European Dioxin Inventory (Quass et al., 2001) suggests an emission factor of 50 ng I-TEQ/kg of zinc with a range of 5 to 500 ng I-TEQ/kg for secondary zinc production. The central value of 50 ng I-TEQ/kg of zinc was selected for all reference years.

The secondary slab zinc production in the United States was 82,500 MT in 1987, 131,000 MT in 1995 and 135,000 MT in 2000 (USGS, 2009b).

7.2.4.2. *Water Releases*

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.2.4.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.2.4.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.2.4.5. *Releases*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Secondary Zinc Production				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Secondary Zinc Production
Air Releases
Emission Factor • 1987—50 ng I-TEQ/kg of zinc. • 1995—50 ng I-TEQ/kg of zinc. • 2000—50 ng I-TEQ/kg of zinc.
Activity Levels • 1987—82,500 MT. • 1995—131,000 MT. • 2000—135,000 MT.
Releases • 1987—4 g I-TEQ. • 1995—7 g I-TEQ. • 2000—7 g I-TEQ.
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.3. PRIMARY FERROUS METAL SMELTING/REFINING

7.3.1. Sinter Production

No changes were made to the release estimates except the air releases in 2000, which decreased slightly due to computational corrections.

7.3.1.1. *Air Releases*

Two types of APCDs are used in sinter production: wet scrubbers and fabric filters. The emission factors for facilities with these two types of APCDs were derived from testing at two U.S. sintering plants operating in 1997 (Calcagni et al., 1998). Activity estimates were derived from several sources: Calcagni et al. (1998), AISI (1990), and Fenton (1996). The release summary below shows the emission factor and activity for each APCD type in each reference year.

7.3.1.2. *Water Releases*

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.3.1.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.3.1.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.3.1.5. *Releases*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Sinter Production				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Sinter Production
Air Releases
Emission Factors ***Wet scrubber*** • 1987—0.62 ng WHO_{98} TEQ_{DF}/kg (0.55 ng I-TEQ_{DF}/kg) of sinter. • 1995—0.62 ng WHO_{98} TEQ_{DF}/kg (0.55 ng I-TEQ_{DF}/kg) of sinter. • 2000—0.62 ng WHO_{98} TEQ_{DF}/kg (0.55 ng I-TEQ_{DF}/kg) sinter. ***Fabric filter*** • 1987—4.6 ng WHO_{98} TEQ_{DF}/kg (4.1 ng I-TEQ_{DF}/kg) of sinter. • 1995—4.6 ng WHO_{98} TEQ_{DF}/kg (4.1 ng I-TEQ_{DF}/kg) of sinter. • 2000—4.6 ng WHO_{98} TEQ_{DF}/kg (4.1 ng I-TEQ_{DF}/kg) of sinter.
Activity Levels[a] • 1987—14.5 MMT. • 1995—12.4 MMT. • 2000—10.6 MMT.
Releases • 1987—33 g WHO_{98} TEQ_{DF} (30 g I-TEQ_{DF}). • 1995—28 g WHO_{98} TEQ_{DF} (25 g I-TEQ_{DF}). • 2000—24 g WHO_{98} TEQ_{DF} (21 g I-TEQ_{DF}).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

[a]Fifty-nine percent of sinter production was at facilities with wet scrubbers and 41% was at facilities with fabric filters.

7.3.2. Coke Production

Minor changes were made to the air emission factor and resulting air-release estimates. The confidence rating was upgraded from preliminary to quantifiable for the air releases due to addition of facility tests used to estimate the emission factor.

7.3.2.1. *Air Releases*

US EPA (2006) used the emission factor of 0.23 ng I-TEQ_{DF}/kg of coal consumed estimated by Bremmer, et al. (1994). Another study measured dioxin emissions at four Canadian facilities (Charles E. Napier Company, Ltd., 2000). The present study averages the emission factor across the facilities tested in both studies to derive an emission factor of 0.29 ng I-TEQ_{DF}/kg of coal consumed. This emission factor was applied to all three reference years. Coke production estimates were obtained from EIA (2002). The confidence rating was upgraded from preliminary to quantitative because the emission factor was derived from two studies involving 5 facilities.

In the year 2000, four facilities with an SIC code for steel works, blast furnaces (including coke ovens), and rolling mills reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 31.8 g, which EPA estimates is equal to 4.1 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

7.3.2.2. *Water Releases*

Although water is used in quench towers to cool hot coke, it is recycled, and the evaporate is replenished. Therefore no water releases occur.

7.3.2.3. *Solid Residue Releases*

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered to be an environmental release.

7.3.2.4. *Products*

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.3.2.5. *Release Summary*

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Coke Production				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Coke Production
Air Releases
Emission Factors • 1987—0.29 ng I-TEQ_{DF}/kg of coal. • 1995—0.29 ng I-TEQ_{DF}/kg of coal. • 2000—0.29 ng I-TEQ_{DF}/kg of coal.
Activity Levels • 1987—33.5 MMT. • 1995—29.9 MMT. • 2000—26.2 MMT.
Releases • 1987—10 g I-TEQ_{DF}. • 1995—9 g I-TEQ_{DF}. • 2000—8 g I-TEQ_{DF}.
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.4. SECONDARY FERROUS METAL SMELTING/REFINING

No changes were made in the release estimates from these facilities.

7.4.1. Air Releases

No changes were made in the air-release estimates, but the confidence rating was upgraded from preliminary to quantifiable. This was based on the support for the emission factor from testing at 6 facilities in Germany and 13 facilities in Canada. The emission factor was derived by averaging the data reported in Umweltbundesamt (1996) and the three Environment Canada reports (Charles E. Napier Company, Ltd., 2000; Cianciarelli, 2000, 2001). Based on the congener data reported by Cianciarelli, 2000, the I-TEQs are approximately equivalent to the WHO_{98} TEQs. The activity estimates were derived from steel-production data from USGS (2002a).

7.4.2. Water Releases

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.4.3. Solid Residue Releases

Although no measurement data were found, CDD/CDFs are likely to be present in the fly ash and possibly other solid residues at these facilities because they have been found in the air emissions. These residues are disposed in landfills and, therefore, are not considered an environmental release.

7.4.4. Products

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.4.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Secondary Ferrous Metal Smelting/Refining				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Secondary Ferrous Metal Smelting/Refining
Air Releases
Emission Factors • 1987—1.2 ng (WHO_{98} or I-TEQ_{DF}/kg) of steel. • 1995—1.2 ng (WHO_{98} or I-TEQ_{DF}/kg) of steel. • 2000—1.2 ng (WHO_{98} or I-TEQ_{DF}/kg) of steel.
Activity Levels • 1987—30.8 MMT. • 1995—38.4 MMT. • 2000—49.0 MMT.
Releases • 1987—37 g (WHO_{98} or I-TEQ_{DF}). • 1995—46 g (WHO_{98} or I-TEQ_{DF}). • 2000—59 g (WHO_{98} or I-TEQ_{DF}).
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.5. FERROUS FOUNDRIES

No changes were made to the release estimates for these facilities, but some additional background information is provided below.

7.5.1. Air Releases

The emission factor for the ferrous foundries was estimated by combining the mean emission factor derived from the data reported in Umweltbundesamt (1996), CARB (1993), and EPA (1997a), yielding a value of 1.23 ng I-TEQ_{DF}/kg of metal feed. This was converted to 1.37 ng WHO_{98} TEQ_{DF}/kg based on the congener profile reported in EPA, 1997a. The emission data represent a total of 10 facilities and generated emission factors ranging over 4 orders of magnitude. Based on the inconsistency of these results for reasons that are not clear, the release estimates are considered preliminary. The activity estimates were derived from survey data from USGS (2001).

In the year 2000, five facilities with an SIC code for gray and ductile iron foundries reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 117 g, which EPA estimates is equal to 21.5 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

7.5.2. Water Releases

Liquid pollution makes up a small portion of the total waste stream from foundries (Freeman, 1995). Water is used in foundries to cool metal and other work pieces and in the wet scrubber air emission system. No information was found on CDD/CDF levels in these wastewaters.

7.5.3. Solid Residue Releases

Solid waste makes up a large portion of the pollution from foundries. One-quarter to one ton of solid waste per one ton of castings is expected (Shah, 1995). The waste comes from sand, slag, emissions control dust, and spent refractories. Molding and core sand make up 66−88% of the total waste from ferrous foundries (U.S. EPA, 1992b).

Slag waste is often very complex chemically and contains a variety of contaminants from the scrap metals. Common components include metal oxides, melted refractories, sand, and coke ash (if coke is used). Fluxes may also be added to help remove the slag from the furnace. Slag may be hazardous if it contains lead, cadmium, or chromium from steel or nonferrous metals melting. Iron foundry slag may be highly reactive if calcium carbide is used to desulfurize the iron. No information was found on CDD/CDF levels in these solid wastes. However, they are typically landfilled and thus not considered a release to environment.

7.5.4. Products

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.5.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Ferrous Foundries				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Ferrous Foundries
Air Releases
Emission Factors • 1987—1.4 ng WHO_{98} TEQ_{DF}/kg (1.2 ng I-TEQ_{DF}/kg) of metal feed. (Preliminary) • 1995—1.4 ng WHO_{98} TEQ_{DF}/kg (1.2 ng I-TEQ_{DF}/kg) of metal feed. (Preliminary) • 2000—1.4 ng WHO_{98} TEQ_{DF}/kg (1.2 ng I-TEQ_{DF}/kg) of metal feed. (Preliminary)
Activity Levels • 1987—9.19 MMT. • 1995—13.9 MMT. • 2000—11.3 MMT.
Releases • 1987—13 g WHO_{98} TEQ_{DF} (11 g I-TEQ_{DF}). (Preliminary) • 1995—19 g WHO_{98} TEQ_{DF} (17 g I-TEQ_{DF}). (Preliminary) • 2000—16 g WHO_{98} TEQ_{DF} (14 g I-TEQ_{DF}). (Preliminary)
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.6. NONFERROUS METAL FOUNDRIES

This is a new section.

7.6.1. Aluminum Foundries

No CDD/CDF emissions data were found for aluminum foundries. However, UNEP (2005) provides a range of emission factors for various types of aluminum processing. For the purposes of a preliminary estimate, a midrange value of 3.5 ng I-TEQ/kg was assumed to apply to all reference years. This corresponds to well-controlled facilities with fabric filters and lime injection.

The activity estimate for aluminum foundries in 2000 was found to be 95,600 MT based on the USGS Minerals Yearbook (USGS, 2000). The earlier years were estimated by assuming that foundry production was a constant ratio with total consumption: 82,500 MT in 1995 and 72,000 MT in 1987.

Foundries typically have solid waste associated with residues from the casting process. No information was found on CDD/CDF levels in these materials. However, these residues would be landfilled and, therefore, are not considered an environmental release.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Aluminum Foundries				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Aluminum Foundries
Air Releases
Emission Factors • 1987—3.5 ng $I\text{-}TEQ_{DF}$/kg of metal feed (Preliminary). • 1995—3.5 ng $I\text{-}TEQ_{DF}$/kg of metal feed (Preliminary). • 2000—3.5 ng $I\text{-}TEQ_{DF}$/kg of metal feed (Preliminary).
Activity Levels • 1987—72,000 MT. • 1995—82,500 MT. • 2000—95,600 MT.
Releases • 1987—0.3 g $I\text{-}TEQ_{DF}$ (Preliminary). • 1995—0.3 g $I\text{-}TEQ_{DF}$ (Preliminary). • 2000—0.3 g $I\text{-}TEQ_{DF}$ (Preliminary).
Water Releases
None.
Solid Residue Releases
None.
Products
None

7.6.2. Copper Foundries

UNEP (2005) provides an emission factor for copper casting operations of 0.03 ng I-TEQ/kg of copper based on emissions testing at foundries in Germany. This was assumed to apply to all reference years.

The activity estimate for copper foundries in 2000 was found to be 26,000 MT based on the USGS Minerals Yearbook (USGS, 2000). The earlier years were estimated by assuming that foundry production was a constant ratio with total consumption: 21,000 MT in 1995 and 18,500 MT in 1987.

Foundries typically have solid waste associated with residues from the casting process. No information was found on CDD/CDF levels in these materials. However, these residues would be landfilled and, therefore, are not considered to be an environmental release.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Aluminum Foundries				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	Q			

Copper Foundries
Air Releases
Emission Factors • 1987—0.03 ng I-TEQ_{DF}/kg of metal feed. • 1995—0.03 ng I-TEQ_{DF}/kg of metal feed. • 2000—0.03 ng I-TEQ_{DF}/kg of metal feed.
Activity Levels • 1987—72,000 MT. • 1995—82,500 MT. • 2000—95,600 MT.
Releases • 1987—<0.1 g I-TEQ_{DF}. • 1995—<0.1 g I-TEQ_{DF}. • 2000—<0.1 g I-TEQ_{DF}.
Water Releases
None.
Solid Residue Releases
None.
Products
None.

7.7. SCRAP ELECTRIC WIRE RECOVERY

No changes were made in the release estimates for these facilities. It is unknown how many facilities in the United States conducted scrap wire recovery operations over the reference years, so no activity estimates could be made, and therefore, no release estimates could be made as well.

7.7.1. Air Releases

As reported in EPA (2006), CDDs/CDFs have been measured in the emissions from these facilities. The emission factor from EPA (1987) of 15.8 ng WHO_{98} TEQ_{DF} (16.9 ng I-TEQ_{DF}/kg) of scrap feed was applied to all reference years. This factor is considered preliminary because it is based on testing at only one facility. Lacking activity information on these facilities; however, no estimates of air releases can be made.

7.7.2. Water Releases

No information was found indicating that these facilities have water effluents.

7.7.3. Solid Residue Releases

Ash is produced as a byproduct when scrap wire is combusted. Harnly et al. (1995) analyzed soil/ash mixtures from three closed metal recovery facilities and from three closed sites using open burning for copper recovery near a California desert town. The geometric means of the total CDD/CDF concentrations at the facility sites and the open burning sites were 86,000 and 48,500 ng/kg, respectively. The geometric mean TEQ concentrations were 2,900 and 1,300 ng I-TEQ_{DF}/kg, respectively. A significantly higher geometric mean concentration (19,000 ng I-TEQ_{DF}/kg) was found in fly ash located at two of the facility sites. Lacking activity information on these facilities, no estimates of releases from solid residues can be made. The portion of the ash that is disposed in landfills would not be considered an environmental release.

7.7.4. Products

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.7.5. Release Summary

The inventory decision criteria and releases to all media are summarized below.

Scrap Electric Wire Recovery
Air Releases
Releases are possible but cannot be quantified (Not quantifiable).
Water Releases
None.
Solid Residue Releases
Releases are possible but cannot be quantified (Not quantifiable).
Products
None.

7.8. DRUM AND BARREL RECLAMATION FURNACES

Changes were made to the activity estimates and resulting air-release estimates from these facilities.

7.8.1. Air Releases

The emission factor estimate (17.5 ng WHO_{98} TEQ_{DF}/drum) was based on testing at a reclamation facility equipped with an afterburner (U.S. EPA, 1987). The testing at this facility indicated that the afterburner achieved a 95% reduction in CDD/CDF emissions. It is possible that some of these facilities do not have afterburners and using this emission factor may underestimate their emissions by 20 times. Based on this uncertainty and data from only one facility, this emission factor is considered preliminary. EPA (2006) reports that 35 million drums were reclaimed in 1997 based on RIPA (1997), and this was assumed for the activity level in 2000. EPA (2006) assumed an activity level of 4.6 million drums in 1987 and 1995 based on a personal communication. These activity assumptions imply a large change in barrel reclamation activity over a short time period, which seems unlikely. Because the RIPA (1997) is a stronger reference, the activity assumptions for 1987 and 1995 were changed to 35 million barrels as well. However, survey data were lacking for all years and these activity estimates are considered preliminary.

7.8.2. Water Releases

No information was found indicating that CDD/CDFs were present in water releases from these facilities.

7.8.3. Solid Residue Releases

Sludges and ashes are stored in collection pits at these facilities. No information was found indicating that CDD/CDFs were present in solid residues from these facilities. However, it is reasonable to assume that CDD/CDFs are present in these ashes because they have been found in the ash from other types of combustion. Lacking measurement information, no estimates of releases from solid residues can be made (Not quantifiable). The portion of the solid waste that is disposed in landfills would not be considered an environmental release.

7.8.4. Products

No information was found indicating that CDD/CDFs were present in products from these facilities.

7.8.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Drum and Barrel Reclamation Furnaces				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	No			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Drum and Barrel Reclamation Furnaces
Air Releases
Emission Factors • 1987—17.5 ng WHO_{98} TEQ_{DF}/drum (16.5 ng I-TEQ_{DF}/drum) (Preliminary). • 1995—17.5 ng WHO_{98} TEQ_{DF}/drum (16.5 ng I-TEQ_{DF}/drum) (Preliminary). • 2000—17.5 ng WHO_{98} TEQ_{DF}/drum (16.5 ng I-TEQ_{DF}/drum) (Preliminary).
Activity Levels • 1987—35 million drums burned. • 1995—35 million drums burned. • 2000—35 million drums burned.
Releases • 1987—0.6 g WHO_{98} TEQ_{DF} (0.6 g I-TEQ_{DF}) (Preliminary). • 1995—0.6 g WHO_{98} TEQ_{DF} (0.6 g I-TEQ_{DF}) (Preliminary). • 2000—0.6 g WHO_{98} TEQ_{DF} (0.6 g I-TEQ_{DF}) (Preliminary).
Water Releases
None.
Solid Residue Releases
Releases are possible but cannot be quantified.
Products
None.

8. CHEMICAL MANUFACTURING AND PROCESSING SOURCES

8.1. BLEACHED CHEMICAL WOOD PULP AND PAPER MILLS

No changes were made to the release estimates for these facilities; however, some additional discussion is provided below to clarify how the estimates were derived.

8.1.1. Air Releases

Air releases from incineration of sludges are covered in Section 3.7.

8.1.2. Water Releases

For 1987 and 1995, an emission-factor approach was not needed because release estimates were available for virtually all facilities. These data came from six industry-wide surveys as described in EPA (2006).

An emission-factor approach was used to estimate releases in 2000 because a comprehensive plant survey was not done for this year. The emission factor and activity estimates were provided by NCASI (Gillespie, 2002) based on data from multiple facilities.

8.1.3. Solid Residue Releases

As described in EPA (2006), the amounts of CDD/CDFs in solid residues came from the comprehensive industry surveys in 1987 and 1995. In 1990, the majority (75.5%) of the wastewater sludge generated by these facilities was placed in landfills or in surface impoundments, with the remainder incinerated (20.5%), applied to land or used as compost (4.1%), or distributed as a commercial product (less than 1%) (U.S. EPA, 1993b). Data on the disposition of wastewater sludges are available only for years 1988 through 1995. On the basis of these data, the best estimate of the amount applied to land (i.e., not incinerated or landfilled) is 14.1 g WHO_{98} or I-TEQ (4.1% of 343 g) for 1987 and 2 g 1 g WHO_{98} or I-TEQ (4.1% of 50 g) for 1995.

For 2000, the primary waste treatment residuals from pulp mills (0.974 million dry MT/year) and the combined, secondary, and dredged waste treatment residuals from pulp mills (1.37 million dry MT/year) were derived from the NCASI database (Gillespie, 2002) on multiple facilities. This yields a total sludge production of

2.34 million dry MT. Fifty-one percent of the sludge generated in 2000 was sent to landfills or lagoons (Gillepsie, 2002). It is uncertain how much of the remaining 49% of the sludge was applied to land. However, a conservative estimate can be developed by applying the 4.1% used to develop the 1987 and 1995 estimates. This implies that 1.19 MMT was landfilled and 0.096 MMT were land applied.

The CDD/CDFs in sludges that are land applied are assumed to represent environmental releases. These amounts are shown in the release summary below. The CDD/CDFs in sludges that are landfilled are not considered to be environmental releases, and these amounts are listed below:

- 1987—260 g WHO_{98} or I-TEQ/year
- 1995—38 g WHO_{98} or I-TEQ/year
- 2000—2 g WHO_{98} or I-TEQ/year

8.1.4. Products

The surveys discussed above provide information on the amounts of CDD/CDFs found in wood pulp: 500 g WHO_{98} or I-TEQ in 1987, 40 g WHO_{98} or I-TEQ in 1995, and 0.6 g WHO_{98} or I-TEQ in 2000. It is unknown if environmental releases occur from paper products made from the pulp. The CDD/CDFs in wood pulp products can be considered to be a reservoir as discussed further in Chapter 11.

8.1.5. Release Summary

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Bleached Chemical Wood Pulp and Paper Mills				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.		Yes	Yes	
Measured emission factors consistent or have understandable differences.		Yes	Yes	
Emission factor tests represent units that are typical of the class.		Yes	Yes	
Activity estimates based on source-specific surveys.		Yes	Yes	
Conclusion (Q = Quantitative, P = Preliminary).		Q	Q	

Bleached Chemical Wood Pulp and Paper Mills
Air Releases
Air releases from incineration of sludges are covered in Section 3.7.
Water Releases
Emission Factor • 2000—0.49 pg (WHO_{98} or I-TEQ/L) of wastewater.
Activity Level • 2000—2.87 trillion L.
Releases • 1987—360 g (WHO_{98} or I-TEQ). • 1995—28 g (WHO_{98} or I-TEQ). • 2000—1 g (WHO_{98} or I-TEQ).
Solid Residue Releases
Emission Factor • 2000—1.8 ng (WHO_{98} or I-TEQ/kg) of sludge.
Activity Level ***Land Applied*** • 2000—0.096 million dry MT.
Releases ***Land Applied*** • 1987—14 g (WHO_{98} or I-TEQ). • 1995—2 g (WHO_{98} or I-TEQ). • 2000—0.2 g (WHO_{98} or I-TEQ).
Products
Releases • 1987—Not quantifiable. • 1995—Not quantifiable. • 2000—Not quantifiable.

8.2. STAND-ALONE CHLOR-ALKALI PLANTS

In the original report, Section 8.2 covered the manufacture of chlorine, chlorine derivatives, and metal chlorides, and Section 8.3 covered the manufacture of halogenated organic chemicals. These two sections have been reorganized into the following three sections:

8.2—Stand-Alone Chlor-Alkali Plants

8.3—Stand-Alone Vinyl Chloride Manufacturing Plants

8.4—Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics

Because the changes to these sections are extensive, they are presented here in their entirety. Although the reorganization is extensive, only minor changes were made to the release estimates.

This section covers plants that produce only chlorine, sodium hydroxide (NaOH), and related caustic chemicals (also known as chlor-alkali plants). These chemicals are also produced at complex plants that produce a variety of chlorinated organic compounds. The CDD/CDF releases associated with chlor-alkali production at these complex plants are covered in Section 8.4.

8.2.1. Process Description

Chlorine gas is produced by electrolysis of brine in electrolytic cells. Three processes are in use: the diaphragm-cell process, the membrane-cell process, and the mercury-cell process. In the diaphragm-cell process, a porous diaphragm divides the electrolytic cell, which contains brine, into an anode compartment and a cathode compartment. When an electric current passes through the brine, the chlorine ions and sodium ions from the salt move to the electrodes. Chlorine gas is produced at the anode, and sodium ions at the cathode react with the water, forming caustic soda. In the membrane-cell process, the compartments are separated by a membrane rather than a diaphragm. Brine is pumped into the anode compartment, and only sodium ions pass into the cathode compartment, which contains pure water. Thus, the caustic soda produced has very little salt contamination. In the mercury-cell process, mercury, which flows along the bottom of the electrolytic cell, serves as the cathode. When an electric current passes through the brine, chlorine is produced at the anode, and sodium dissolves in the mercury, forming an amalgam of sodium and mercury (Chorine Institute, 2010).

Until the late 1970s, the primary type of electrolytic process used in the chlor-alkali industry to produce chlorine consisted of the use of mercury cells containing graphite electrodes. During the 1980s, titanium metal anodes were developed to replace graphite electrodes (U.S. EPA, 1982; Curlin and Bommaraju, 1991). Currently, no U.S. facility is believed to use graphite electrodes in the production of chlorine gas (telephone conversation between L. Phillips, Versar, Inc., and T. Fielding, U.S. EPA, Office of Water, February 1993).

8.2.2. Regulations

Although EPA does not regulate CDDs/CDFs specifically, it issued restrictions under RCRA on the land disposal of wastewater and sludges generated by chlorine manufacturers that use the mercury-cell process and the diaphragm-cell process (with graphite electrodes) (waste codes K071, K073, and K106) (40 CFR 268).

8.2.3. Literature

As shown in Table 8-1, high levels of CDFs have been found in several samples of graphite electrode sludge from facilities in Europe. The CDFs predominate in these sludges, and the 2,3,7,8-substituted congeners account for a large fraction of the respective congener totals (Rappe et al., 1990, 1991; Rappe, 1993; Strandell et al., 1994). Although the origin of the CDFs in graphite electrode sludge is uncertain, chlorination of the cyclic aromatic hydrocarbons (such as dibenzofuran) present in the coal tar used as a binding agent in the graphite electrodes has been proposed as the primary source (Strandell et al., 1994). For this reason, sludges produced using metal electrodes were not expected to contain CDFs. However, results of an analysis of metal electrode sludge from a facility in Sweden, analyzed as part of the Swedish Dioxin Survey, showed that the sludge contained high levels of CDFs (similar to those of the graphite sludge) and primarily nondetectable levels of CDDs (Strandell et al., 1994). The sludge showed the same type of CDF congener pattern reported by Rappe et al. (1991) and Rappe (1993). Strandell et al. suggested that chlorination of polyaromatic hydrocarbons present in the rubber linings of the electrolytic cell may have produced the CDFs found in the one sample analyzed.

The Chlorine Chemistry Council (CCC), a trade association representing manufacturers that produce and/or use chlorine, sampled a variety of waste streams at seven stand-alone chlor-alkali facilities in the United States (CCC, 2004). Note that one of these plants (Occidental in Deer Park, TX) also produced vinyl chloride monomer (VCM), but the processes and associated waste streams are adequately separated such that it can be treated as a stand-alone facility. This information is also summarized in Dyke and Amendola (2007). This study measured CDD/CDF releases to water from all seven facilities as summarized in Table 8-2. Air releases were only detected at one facility (see Table 8-3). Dyke and Amendola (2007) summarized the amount of CDD/CDF in all waste streams and provided a confidence rating for each value (see Table 8-4). Table 8-4 shows the amount of CDD/CDFs that are sent to off-site incinerators, landfills, and deep-well injection facilities. The releases from incineration are included in the estimates presented for hazardous waste incinerators (see Section 3.2). The amounts sent to secure landfills and deep-well injection facilities are not considered to be environmental releases.

Dyke and Amendola (2007) present release estimates for both the years 2000 and 2002. The 2002 values are not reproduced here but are generally lower or similar to the 2000 values.

In the year 2000, five facilities with an SIC code for alkalies and chlorine reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 204 g, which EPA estimates is equal to 3.3 g WHO_{98} TEQ_{DF}. The sum of the water releases across these facilities was 1,416 g, which EPA estimates is equal to 24.8 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

8.2.4. Releases

The information presented in Dyke and Amendola (2007) was selected as the best basis for estimating CDD/CDF releases from these facilities. The seven stand-alone chlor-alkali plants covered in this study are believed to represent most of the stand-alone chlor-alkali production in the United States. Therefore, it was unnecessary to develop emission factors to estimate releases from untested facilities. The Dyke and Amendola release estimates are specific to the year 2000. No release data were found for earlier years. Because the chemical production rates and technologies used at these facilities were probably similar in 1995 and 2000, the 2000 results are assumed to apply to 1995. However, significant changes may have occurred since 1987, so no release estimates could be made for 1987. The releases to all media are presented in Table 8-4 and summarized below.

The solid residues from these plants are disposed in secure landfills or by deep-well injection and, therefore, are not considered an environmental release. The amounts are summarized below:

- 1987—Not Available

- 1995—2.7 g I-TEQ
- 2000—2.7 g I-TEQ

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Stand-Alone Chlor-Alkali Plants				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes	Yes	`	
Measured emission factors consistent or have understandable differences.	Yes	Yes		
Emission factor tests represent units that are typical of the class.	Yes	Yes		
Activity estimates based on source-specific surveys.	Yes	Yes		
Conclusion (Q = Quantitative, P = Preliminary).	Q	Q		

Stand-Alone Chlor-Alkali Plants
Air Releases
• 1987—Not available. • 1995—0.03 g I-TEQ. • 2000—0.03 g I-TEQ.
Water Releases
• 1987—Not available. • 1995—2 g I-TEQ. • 2000—2 g I-TEQ.
Solid Residue Releases
None. The solid residues from these plants are disposed in secure landfills or by deep-well injection and, therefore, are not considered an environmental release.
Products
No information was found suggesting that CDD/CDFs are found in the products from these facilities.

8.3. STAND-ALONE VINYL CHLORIDE MANUFACTURING PLANTS

As explained at the beginning of Section 8.2, this is a new section based on the reorganization of Sections 8.2 and 8.3 in the original report. This section covers plants that produce only polyvinyl chloride (PVC) and PVC intermediates such as ethylene dichloride (EDC) and VCM. These chemicals are also produced at complex plants that produce a variety of chlorinated organic compounds. The CDD/CDF releases associated with vinyl chloride production at these complex plants are covered in Section 8.4.

8.3.1. Process

PVC resins are produced from the polymerization of VCM. VCM is typically produced by the thermal dehydrochlorination (commonly known as cracking) of EDC. The cracking of EDC requires elevated pressure (20 to 30 atm) and temperature (450 to 650EC) and yields VCM and HCl at about a 1:1 molar ratio. EDC is produced by two different methods: (1) direct chlorination of ethylene with chlorine in the presence of a catalyst at a temperature of 50 to 60EC and pressure of 4 to 5 atm; and (2) oxychlorination, which involves reaction of ethylene with HCl and oxygen in the presence of a catalyst at temperatures generally less than 325EC. The primary source of HCl for the oxychlorination process is the HCl produced from the cracking of EDC to form VCM. Most VCM manufacturing facilities are integrated with EDC production facilities (The Vinyl Institute, 1998).

8.3.2. Regulations

Although EPA regulates emissions from EDC/VCM production facilities under the Clean Water Act (40 CFR 61), the Clean Air Act (40 CFR 414), and RCRA (40 CFR 268, waste codes F024, K019, and K020), CDDs/CDFs are not specifically regulated pollutants.

8.3.3. Literature

Although it has been generally recognized that CDDs/CDFs can be formed during the manufacture of EDC, VCM, and PVC, manufacturers and environmental public interest groups have disagreed as to the quantity of CDDs/CDFs that are formed and released to the environment in wastes and possibly in PVC products. Greenpeace International initially determined that CDDs and CDFs can be formed during the manufacture of PVC. In 1993, it issued a report on CDD/CDF emissions associated with the production of EDC/VCM (Greenpeace, 1993).

Greenpeace estimated that 5 to 10 g I-TEQ_{DF} were released to the environment (air, water, and ground combined) annually for every 100,000 MT of VCM produced. This emission factor was based on data gathered by Greenpeace on four European plants. The Vinyl Institute responded with a critique of the Greenpeace report (ChemRisk, 1993). Miller (1993) summarized the differing views of the two parties. According to Miller, European PVC manufacturers claimed the emission factor was 0.01 to 0.5 g I-TEQ_{DF}/100,000 MT of VCM, and although Greenpeace and ChemRisk used basically the same monitoring information to develop their emission factors, Greenpeace adjusted the emission factor to account for unquantified fugitive emissions and waste products that contain unspecified amounts of CDDs/CDFs.

In 1995, Greenpeace issued a second report (Stringer et al., 1995) reiterating the organization's concern that the generation and the emission of CDDs/CDFs may be significant and urging that further work be initiated to quantify and prevent emissions. Stringer et al. (1995) presented the results of analyses of three samples of chlorinated wastes obtained from U.S. EDC/VCM manufacturing facilities. The three samples were characterized according to EPA hazardous waste classification numbers as an F024 waste (waste from the production of short-chain aliphatics by free radical-catalyzed processes), a K019 waste (heavy ends from the distillation of ethylene from EDC production), and a probable K020 waste (heavy ends from distillation of vinyl chloride in VCM manufacturing). Table 8-5 presents the analytical results reported by Stringer et al. (1995). This study acknowledged that because EDC/VCM production technologies and waste treatment and disposal practices are very site-specific, the limited information available on CDD/CDF generation and emissions made it difficult to quantify amounts of CDDs/CDFs generated and emitted.

In response to the lack of definitive studies, and at the recommendation of the EPA, U.S. PVC manufacturers began an extensive monitoring program—the Dioxin Characterization Program (DCP). The objective of the DCP was to evaluate the extent and magnitude of potential CDD/CDF releases to air, water, and land, as well as the potential for PVC product contamination. Manufacturers performed emissions and product testing at several facilities that were representative of various manufacturing and process control technologies. In 1998, The Vinyl Institute completed studies of CDD/CDF releases in wastewater, wastewater treatment plant solids, and stack gases, as well as studies of the CDD/CDF content of products (PVC resins and EDC sold as products) (The Vinyl Institute, 1998). This study presented results for

22 samples from 14 of the 24 U.S. and Canadian facilities manufacturing suspension and mass PVC resins (13 pipe resins, 3 bottle resins, and 6 packaging resins). The results for U.S. manufacturers are summarized in Table 8-6. The 14 sampled sites represented approximately 74% of estimated 1995 U.S. and Canadian suspension and mass PVC resin production. CDDs/CDFs were detected in only one sample (0.043 ng I-TEQ_{DF}/kg, assuming nondetects equal to zero). The overall mean TEQ concentrations were 0.002 ng I-TEQ_{DF}/kg (assuming nondetects equal to zero) and 0.7 ng I-TEQ_{DF}/kg (assuming nondetects equal to one-half the DL). The DLs were 2 ng/kg or less for all congeners in all samples except for OCDD and OCDF, which had DLs of 6 ng/kg or less.

The same study also presented results for six samples from four of the seven U.S. facilities manufacturing dispersion PVC resins. CDDs/CDFs were detected in five of the samples. The results are summarized in Table 8-6. In terms of production, the four sampled sites represent approximately 61% of estimated 1995 U.S. dispersion PVC resin production. The results ranged from not detected to 0.008 ng I-TEQ_{DF}/kg (overall mean = 0.001 ng I-TEQ_{DF}/kg, assuming nondetects equal to zero, and 0.4 ng I-TEQ_{DF}/kg, assuming nondetects equal to one-half the DL). The DLs were 2 ng/kg or less for all congeners in all samples except for OCDD and OCDF, which had DLs of 4 ng/kg or less.

Results were also presented for five samples from 5 of the 15 U.S. facilities manufacturing EDC. The results are summarized in Table 8-6. In terms of production, the five sampled sites represented approximately 71% of the estimated EDC produced in the United States in 1995. CDDs/CDFs were detected in only one sample (0.03 ng I-TEQ_{DF}/kg). The overall mean TEQ concentrations were 0.006 ng I-TEQ_{DF}/kg (nondetects equal to zero) and 0.21 ng I-TEQ_{DF}/kg (nondetects equal to one-half the DL). The DLs for all congeners were 1 ng/kg or less.

EPA (2006) used concentration and production data to estimate that vinyl chloride contained 0.02 g I-TEQ in 1995 and 0.02 g I-TEQ in 2000. It is unknown if releases occurred from these products.

The Chlorine Chemistry Council (CCC), a trade association representing manufacturers that produce and/or use chlorine, also sponsored studies to measure CDD/CDF releases from the production of chlorine and chlorinated organics. The information from The Vinyl Institute and CCC studies was summarized in a recent article by Dyke and Amendola (2007). This article identifies two facilities as stand-alone vinyl chloride plants. Dyke and Amendola (2007) summarized the releases of CDD/CDF to all media for the year 2000 and provided a confidence rating for each value analogous to one used in this report (see Table 8-7). Dyke and Amendola (2007) presented release estimates for both the years 2000 and 2002. The 2002 values are not reproduced here but are generally lower or similar to the 2000 values.

8.3.4. Releases

The information presented in Dyke and Amendola (2007) was selected as the best basis for estimating CDD/CDF releases from these facilities. The two stand-alone vinyl chloride plants covered in this study are believed to represent most of the stand-alone vinyl chloride production in the United States. Therefore, it was not necessary to develop emission factors to estimate releases from untested facilities. The Dyke and Amendola (2007) release estimates are specific to the year 2000. Since the chemical production rates and technologies used at these facilities have changed significantly since 1987, release estimates cannot be made for 1987 and 1995.

Table 8-7 shows the amount of CDD/CDFs that are sent to off-site incinerators and landfills. The releases from incineration are included in the estimates presented for hazardous waste incinerators (see Section 3.2). The amount sent to secure landfills (5.57 g I-TEQ in 2000) is not considered to be an environmental release.

As discussed above, several studies have detected CDD/CDFs in PVC products. However, no information is available on possible releases from these products, and therefore, they are a potential but unquantifiable source (Not quantifiable).

The releases to all media from the stand-alone vinyl chloride plants are presented in Table 8-7.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Stand-Alone Vinyl Chloride Manufacturing Plants				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes	Yes		
Measured emission factors consistent or have understandable differences.	Yes	Yes		
Emission factor tests represent units that are typical of the class.	Yes	Yes		
Activity estimates based on source-specific surveys.	Yes	Yes		
Conclusion (Q = Quantitative, P = Preliminary).	Q	Q		

Stand-Alone Vinyl Chloride Manufacturing Plants
Air Releases
• 1987—Not available. • 1995—Not available. • 2000—0.62 g I-TEQ.
Water Releases
• 1987—Not available. • 1995—Not available. • 2000—<0.1 g I-TEQ.
Solid Residue Releases
None. The solid residues from these plants are disposed in secure landfills and, therefore, are not considered to be an environmental release.
Products
Not quantifiable.

8.4. COMPLEX CHEMICAL PLANTS PRODUCING CHLORINE AND A VARIETY OF CHLORINATED ORGANICS

As explained at the beginning of Section 8.2, this is a new section based on the reorganization of Sections 8.2 and 8.3 in the original report. This section describes CDD/CDF releases from facilities that produce combinations of chlorine and multiple chlorinated organic chemicals. The plants that exclusively manufacture chlorine are covered in Section 8.2, and the plants that exclusively produce vinyl chloride are covered in Section 8.3.

The waste streams at these complex plants are typically combined, which prevents derivation of chemical-specific release estimates. Instead, a facility-specific approach has been used where the releases for each plant are estimated on the basis of the CDD/CDF levels and total flow rates measured at the final release point.

These plants currently—or have in the past—produced a variety of chemicals that have been associated with CDD/CDF releases. These include chlorine, vinyl chloride, chlorophenols, chlorobenzenes, and chlorobiphenyls. Background information on the regulations, processes, and products related to chlorine and vinyl chloride products were presented in Sections 8.2 and 8.3, respectively. Therefore, they are not repeated in this section. The production and use of chlorophenols, chlorophenoxy herbicides, and PCB products are now banned or strictly regulated in most countries. PCB production ceased prior to the first reference year, i.e., 1987. So CDD/CDF releases associated with PCB production are not covered in this report (PCB releases from nonproduction contemporary sources are covered in Chapter 10, and releases from reservoirs are covered in Chapter 11).

Section 8.4 first presents separate discussions on chlorophenol and chlorobenzenes. These discussions describe the manufacturing processes, regulations, and products for these chemical groups. Then the section presents the release estimates occurring during production activities at the complex plants.

8.4.1. Chlorophenols

8.4.1.1. *Process Description*

The two major commercial methods used to produce chlorophenols are (1) electrophilic chlorination of molten phenol by chlorine gas in the presence of catalytic amounts of a metal chloride and organic chlorination promoters and stabilizers, and (2) alkaline hydrolysis of chlorobenzenes under heat and pressure using aqueous methanolic sodium hydroxide. Other manufacturing methods include conversion of diazonium salts of various chlorinated anilines and chlorination of phenolsulfonic acids and benzenesulfonic acids, followed by the removal of the sulfonic acid group (Gilman et al., 1988; Hutzinger and Fiedler, 1991b).

8.4.1.2. *Regulations for Chlorophenols*

In 1983, EPA cancelled the sale of Silvex and 2,4,5-T for all uses (Federal Register, 1987a). Earlier, in 1979, EPA had ordered emergency suspension of the forestry, rights-of-way, and pasture uses of 2,4,5-T. Emergency suspensions of the forestry, rights-of-way, pasture, home and garden, commercial/ornamental turf, and aquatic weed control/ditch bank uses of Silvex were also ordered (Federal Register, 1979; Plimmer, 1980). The home and garden, commercial/ornamental turf, and aquatic weed control/ditch bank uses of 2,4,5-T had been suspended in 1970.

Pentachlorophenol (PCP) was one of the most widely used biocides in the United States prior to the regulatory actions to cancel and restrict certain of its wood and nonwood preservative uses. PCP was registered for use as a herbicide, defoliant, mossicide, and mushroom house biocide. It also found use as a biocide in pulp-paper mills, oil wells, and cooling towers. These latter three uses were terminated on or before 1993 (U.S. EPA, 1993b). However, the major use (greater than 80% of consumption) of PCP was and continues to be wood preservation. An overview of the history of the PCP pesticide rules is presented below.

In 1984, EPA issued a notice of intent to cancel registrations of pesticide products containing PCP (including its salts) for all wood preservative uses (Federal Register, 1984). This notice specified modifications to the terms and conditions of product registrations that were required in order to avoid cancellation of the products. In response to this notice, several trade associations and registrants requested administrative hearings to challenge EPA's determinations. After considering the comments and alternatives suggested during the prehearing stage of the administrative proceedings, EPA concluded that certain changes to the 1984 notice were appropriate. These changes, finalized in 1986 (Federal Register, 1986), included the following: (a) all wood preservative uses of PCP and its salts were classified as "restricted use" only by certified applicators, (b) specific worker protection measures were required, (c) limits were placed on the HxCDD content of PCP, and (d) label restrictions for home and farm uses of PCP prohibited its application indoors and to wood intended for interior use (with a few exceptions) as well as its application in a manner that might result in direct exposure of domestic animals or livestock or in the contamination of food, feed, or drinking and irrigation water.

EPA subsequently amended its notice on the wood preservative uses to establish reliable and enforceable methods for implementing certified limits for HxCDD and 2,3,7,8-TCDD in registered wood preservative pesticide products (Federal Register, 1987b). Levels of 2,3,7,8-TCDD were not allowed to exceed 1 ppb in any product, and after February 2, 1989, 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 (a gradually phased-in requirement). On January 21, 1987, EPA prohibited the registration of PCP and its salts for most nonwood uses (Federal Register, 1987c). EPA deferred action on several uses (uses in pulp/paper mills, oil wells, and cooling towers) pending receipt of additional exposure, use, and ecological effects data. On January 8, 1993, EPA issued a press advisory stating that its special review of these deferred nonwood uses was being terminated because all of these uses had been either voluntarily cancelled by the registrants or cancelled by EPA for failure of the registrants to pay the required annual maintenance fees (U.S. EPA, 1993b).

Di- and trichlorophenol manufacturers are subject to reporting under the Dioxin/Furan Test Rule, which is discussed in Section 8.3.7 of the original report. Since the effective date of that rule (June 5, 1987), only the 2,4-dichlorophenol isomer has been commercially produced in (or imported to) the United States, and as noted in Table 8-8, no CDDs/CDFs were detected in the product. Testing is required for the other di- and trichlorophenols if manufacture or importation resumes. Similarly, tetrachlorophenols were subject to reporting under the Dioxin/Furan Pesticide Data Call-In (discussed in Section 8.3.8 of the original report). Since issuance of the Data Call-in, the registrants of tetrachlorophenol-containing pesticide products have elected to no longer support the registration of their products in the United States.

In the mid-1980s, the EPA Office of Solid Waste (OSW) promulgated, under RCRA, land disposal restrictions on wastes (wastewaters and nonwastewaters) resulting from the manufacture of chlorophenols (40 CFR 268). Table 8-9 lists all wastes in which CDDs/CDFs are specifically regulated by EPA as hazardous constituents, including chlorophenol wastes (waste codes F020 and F021). The regulations prohibit the land disposal of these wastes until they are treated to a level below the routinely achievable DLs for the EPA hazardous waste numbers listed in Table 8-9 for each of the following congener groups: TCDDs, PeCDDs, HxCDDs, TCDFs, PeCDFs, and HxCDFs. Wastes from PCP-based wood-preserving operations (waste codes K001 and F032) are also regulated as hazardous wastes under RCRA (40 CFR 261).

The EPA Office of Water promulgated effluent limitations for facilities that manufacture chlorinated phenols and discharge treated wastewater (40 CFR 414.70). These effluent limitations do not specifically regulate CDDs or CDFs. The effluent limitations for the individually regulated chlorinated phenols are less than or equal to 39 μg/L for facilities that use biological end-of-pipe treatment.

8.4.1.3. *Products—Chlorophenols*

Chlorophenols have been widely used for a variety of pesticidal applications. The higher-chlorinated phenols (tetrachlorophenol and PCP) and their sodium salts have been used primarily for wood preservation. The lower-chlorinated phenols have been used primarily as chemical intermediates in the manufacture of other pesticides. For example, 2,4-dichlorophenol is used to produce the herbicides 2,4-dichlorophenoxyacetic acid (2,4-D), 4-(2,4-dichlorophenoxy)butanoic acid (2,4-DB), 2-(2,4-dichlorophenoxy)-propanoic acid (2,4-DP), Nitrophen, Genite, and Zytron, and 2,4,5-trichlorophenol was used to produce hexachlorophene, 2,4,5-T, Silvex, Erbon, Ronnel, and Gardona (Gilman et al., 1988; Hutzinger and Fiedler, 1991b).

Because of the manufacturing processes employed, commercial chlorophenol products can contain appreciable amounts of impurities (Gilman et al., 1988). During the direct chlorination of phenol, CDDs/CDFs can form either by the condensation of tri-, tetra-, and pentachlorophenols or by the condensation of chlorophenols with hexachlorocyclohexadienone (which forms from excessive chlorination of phenol). During alkaline hydrolysis of chlorobenzenes, CDDs/CDFs can form through chlorophenate condensation (Ree et al., 1988; Gilman et al., 1988; Hutzinger and Fiedler, 1991b)

The limited information on CDD/CDF concentrations in chlorophenols published in the 1970s and early 1980s was compiled by Versar, Inc. (1985) and Hutzinger and Fiedler (1991b). The results of several major studies cited by these reviewers (Firestone et al., 1972; Rappe and Marklund, 1978; Rappe et al., 1978) are presented in Table 8-8. Typically, CDDs/CDFs were not detected in mono- and dichlorophenols but were reported in tri- and tetrachlorophenols. More recent results of testing of 2,4-dichlorophenol, performed in response to the Toxic Substances Control Act (TSCA) dioxin/furan test rule, showed no detectable concentrations of 2,3,7,8-substituted tetra- through hepta-CDD/CDFs.

Detailed information on 2,4,5-T production and 2,3,7,8-TCDD levels was presented in Chapter 11 of the original report. Production of 2,4,5-T during the 1950s, 1960s, and 1970s was estimated as 2,000, 4,000, and 1,500 MT/year, respectively. This was combined with estimates of 2,3,7,8-TCDD levels in the product to estimate that the cumulative amount of 2,3,7,8-TCDD in 2,4,5-T used over the period of 1950 to 1979 was 36,000 g. No product release estimates are presented for the reference years because production ceased prior to 1987. After the chemical was applied, it would have become incorporated into the soil reservoir. The potential amounts of 2,3,7,8-TCDD remaining in the soil reservoir and possible releases are discussed in Chapter 11.

The production of PCP for wood preserving began on an experimental basis in the 1930s. In 1947, nearly 3,200 MT of PCP were reported to have been used in the United States by the commercial wood preserving industry. Use in this industry steadily increased through the mid-1970s (AWPI, 1977). Although domestic consumption volumes are not available for all years, it is estimated, on the basis of historical production/export data for PCP reported in Mannsville (1983), that 90 to 95% of production volume has typically been consumed domestically rather than exported. A reasonable estimate of total domestic PCP consumption during the period of 1970 to 1995 is about 400,000 MT. This estimate assumes an average annual consumption rate of 20,000 MT/year during the 1970s, 15,000 MT/year during the 1980s, and 10,000 MT/year during the 1990s.

Table 8-10 presents a compilation of published data on the CDD/CDF content of technical-grade PCP. The only samples that have been analyzed for all dioxin-like CDDs/CDFs were manufactured in the mid-to-late 1980s. Figure 8-1 presents these data in graphical form. It shows that the predominant congener groups are OCDD, OCDF, and HpCDD, Waddell et al. (1995) tested analytical-grade PCP (from Aldrich Chemical Co.) for CDD/CDF content and found the same congener profile; however, the CDD/CDF levels were three to four orders of magnitude lower. Table 8-11 presents a similar compilation of published data on the CDD/CDF content of PCP-Na. The table shows the same patterns of dominant congeners and congener groups reported for PCP

Samples of technical-grade PCP manufactured during the mid-to-late 1980s contained about 1.7 mg WHO_{98} TEQ_{DF}/kg (3 mg I-TEQ/kg), based on the data presented in Table 8-10. No published reports could be located that present the results of any congener-specific analyses of PCP manufactured since the late 1980s. However, monthly measurements of CDD/CDF congener group concentrations in technical PCP manufactured for use in the United States have been reported to EPA from 1987 to the present (letter dated March 5, 1997, from Thomas Mitchell, KMG-Bernuth, to Matthew Lorber, U.S. EPA; letter dated February 7, 1997, from John Wilkinson, Pentachlorophenol Task Force, to Matthew Lorber, U.S. EPA; U.S. EPA, 1999a). The average congener group concentrations reported to EPA for the years 1988 (i.e., 1 year after EPA regulations were imposed limiting HxCDD and 2,3,7,8-TCDD concentrations in PCP) to 1999 are presented in Table 8-10. In general, the average congener group concentrations during the period of 1988 to 1999 are lower by a factor of 2 to 4 than the concentrations observed in the mid-to-late 1980 (based on the full-congener analysis of samples). If it is assumed that the toxic CDD/CDF congeners have also been reduced by a similar factor, then the TEQ content of PCP manufactured since 1988 is about 0.6 mg WHO_{98} TEQ_{DF}/kg (1 mg I-TEQ/kg).

An estimated 12,000 MT of PCP were used for wood preservation in the United States in 1987 (WHO, 1991). An estimated 8,400 MT were used in 1994 (AWPI, 1995); for the purposes of this report, it is assumed that an identical amount was used in 1995. In 1999, approximately 7,710 MT of PCP were produced annually in the United States (Council of Great Lakes Industries, 1999); for the purposes of this report, it is assumed that an identical amount was produced in 2000. Assuming that 95% of the production volume was consumed domestically (Mannsville, 1983) and that all of the PCP produced in 2000 was used for wood preservation, approximately 7,325 MT of PCP were used in the United States for wood preservation. Combining these activity level estimates with the TEQ concentration estimates presented above indicates that 20,000 g WHO_{98} TEQ_{DF} (36,000 g I-TEQ_{DF}), 4,800 g WHO_{98} TEQ_{DF} (8,400 g I-TEQ_{DF}), and 4,200 g WHO_{98} TEQ_{DF} (7,300 g I-TEQ_{DF}) were incorporated into PCP-treated wood products in 1987, 1995, and 2000, respectively. It is unknown how much of the CDD/CDFs escape from the wood into the environment. Several field studies (Gurprasad et al., 1995; EPRI, 1995; Wan, 1995; Wan and Van Oostdam, 1995) demonstrate that CDDs/CDFs do apparently leach into soil from PCP-treated wood, but the studies do not provide release-rate data. No studies were located that provide any measured CDD/CDF volatilization rates from PCP-treated wood. Although CDDs/CDFs have very low vapor pressures, they are not bound to, nor do they react with, the wood in any way that would preclude volatilization. Lorber et al. (2002) compared the spatial distribution of CDD/CDF congeners in PCP-treated poles of different ages. A trend for dioxins to concentrate in the outer portions of the pole over time suggests migration within the poles, and this migration may result in some environmental release. However, this study could not quantify such releases. Several studies (Bremmer et al. [1994], Rappe [1995], Eduljee and Dyke [1996] and Douben et al. [1995]) have attempted to estimate potential CDD/CDF volatilization releases using conservative assumptions or modeling approaches, but these estimates span many orders of magnitude. Therefore, no estimate could be made as to what portion of the CDD/CDFs in products are released to the environment (Not quantifiable). The cumulative amounts of CDD/CDFs in PCP-treated wood can also be considered a potential reservoir source (see Chapter 11 for further discussion of this issue).

8.4.1.4. *Products—2,4-D*

Although 2,4-Dichlorophenoxyacetic acid (2,4-D) is not a true chlorophenol, it is included in this section because it is produced from chlorophenols and, therefore, is closely associated. The available information on 2,4-D production and CDD/CDF levels was summarized in Chapter 11 of the original report. An estimated 28,100 MT of 2,4-D were used in the United States in 2000, making it one of the top 10 pesticides in terms of quantity used (EPA proprietary data). The pesticide 2,4-D is judged to have the potential for environmental release through its agricultural use. Since 1995, the chemical manufacturers of 2,4-D have been undertaking voluntary actions to significantly reduce the dioxin content of the product. No information is available on the level of dioxin contamination, if any, that may have been present in 2,4-D in 2000. An estimated 26,300 and 30,400 MT were used during 1995 and 1987, respectively (U.S. EPA, 1997c, 1988). On the basis of the average CDD/CDF congener concentrations in 2,4-D (not including OCDD and OCDF), the corresponding WHO_{98} TEQ_{DF} concentration is 1.1 μg/kg (0.7 μg I-TEQ_{DF}/kg). Combining this TEQ concentration with the activity level estimates for 1995 and 1987 indicates that 28.9 g WHO_{98} TEQ_{DF} (18.4 g I-TEQ_{DF}) were released in 1995 and 33.4 g WHO_{98} TEQ_{DF} (21.3 g I-TEQ_{DF}) was released in 1987. No estimate can be made for 2000 because of the poor quality of existing information.

8.4.2. Chlorobenzenes

8.4.2.1. *Process Description*

Chlorobenzenes can be produced via three methods: (1) electrophilic substitution of benzene (in liquid or vapor phase) with chlorine gas in the presence of a metal salt catalyst,

(2) oxidative chlorination of benzene with HCl at 150 to 300EC in the presence of a metal salt catalyst, and (3) dehydrohalogenation of hexachlorocyclohexane wastes at 200 to 240EC with a carbon catalyst to produce trichlorobenzene, which can be further chlorinated to produce higher-chlorinated benzenes (Ree et al., 1988; Hutzinger and Fiedler, 1991b; Bryant, 1993).

All chlorobenzenes currently manufactured in the United States are produced by the electrophilic substitution process using liquid-phase benzene (i.e., temperature is at or below 80EC). $FeCl_3$ is the most common catalyst employed. Although this method can be used to produce mono- through hexachlorobenzene, the extent of chlorination is controlled to yield primarily monochlorobenzene and dichlorobenzene. The finished product is a mixture of chlorobenzenes, and refined products must be obtained by distillation and crystallization (Bryant, 1993).

8.4.2.2. *Regulations for Chlorobenzenes*

EPA determined, as part of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Data Call-In, that the 1,4-dichlorobenzene manufacturing processes used in the United States are not likely to form CDDs/CDFs. Mono-, di-, and trichlorobenzene are listed as potential precursor chemicals under the TSCA dioxin/furan test rule and are subject to reporting. In addition, EPA issued a Significant New Use Rule (SNUR) under Section 5(a)(2) of TSCA on December 1, 1993 (effective January 14, 1994) for pentachlorobenzene and 1,2,4,5-tetrachlorobenzene (Federal Register, 1993). This rule requires that EPA be notified at least 90 days before the manufacture, import, or processing of either of these compounds in amounts of 10,000 pounds or greater per year per facility for any use. All registrations of pesticide products containing hexachlorobenzene were cancelled in the mid-1980s (Carpenter et al., 1986).

OSW promulgated land disposal restrictions on wastes (i.e., wastewaters and nonwastewaters) resulting from the manufacture of chlorobenzenes (40 CFR 268). Table 8-9 lists all solid wastes for which EPA specifically regulates CDDs and CDFs, including chlorobenzene wastes, as hazardous constituents. The regulations prohibit the land disposal of these wastes until they are treated to a level below the routinely achievable DLs in the waste extract listed in Table 8-9 for each of the following congener groups: TCDDs, PeCDDs, HxCDDs, TCDFs, PeCDFs, and HxCDFs.

The EPA Office of Water promulgated effluent limitations for facilities that manufacture chlorinated benzenes and discharge treated wastewater (40 CFR 414.70). These effluent limitations do not specifically address CDDs and CDFs. The following chlorinated benzenes are regulated: chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobenzene. The effluent limitations for the individual regulated chlorinated benzenes are less than or equal to 77 μg/L for facilities that use biological end-of-pipe treatment and less than or equal to 196 μg/L for facilities that do not use biological end-of-pipe treatment.

Since at least 1993, U.S. commercial production of chlorobenzenes has been limited to monochlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and, to a much lesser extent, 1,2,4-trichlorobenzene. As noted above, CDD/CDF formation is not expected under the normal operating conditions of the processes currently used in the United States to produce these four chemicals. No tetra-, penta-, or hexachlorinated benzenes are now intentionally produced or used in the United States (Bryant, 1993). Thus, releases of CDDs/CDFs from the manufacture of chlorobenzenes in 1995 were estimated to be negligible. Because the information available on CDD/CDF content of mono-through pentachlorobenzene is very limited and is based primarily on unpublished European data, and because information on the chlorobenzene manufacturing processes in place during 1987 is not readily available, no emission estimates can be made for 1987.

8.4.2.3. *Products—Chlorobenzenes*

Chlorobenzenes have been produced in the United States since 1909. U.S. production operations were developed primarily to provide chemical raw materials for the production of phenol, aniline, and various pesticides based on the higher-chlorinated benzenes. Because of (incremental) changes in the processes used to manufacture phenol and aniline and the phaseout of highly chlorinated pesticides such as DDT and hexachlorobenzene, U.S. production of chlorobenzenes in 1988 had decreased to 50% of the peak production level, in 1969.

CDDs/CDFs can be produced inadvertently during the manufacture of chlorobenzenes by nucleophilic substitution and pyrolysis mechanisms (Ree et al., 1988). The criteria required for production of CDDs/CDFs via nucleophilic substitution are oxygen as a nuclear substituent (i.e., presence of chlorophenols) and production or purification of the substance under alkaline conditions. Formation via pyrolysis requires reaction temperatures above 150°C (Ree et al., 1988; Hutzinger and Fiedler, 1991b). The liquid-phase electrophilic substitution process currently used in the United States does not meet either of these criteria. Although Ree et al. (1988) and Hutzinger and Fiedler (1991b) state that the criteria for formation of CDDs/CDFs via nucleophilic substitution may be present in the catalyst neutralization and purification/distillation steps of the manufacturing process; Opatick (1995) states that the chlorobenzene reaction product in U.S. processes remains mildly acidic throughout these steps.

Table 8-12 summarizes the very limited published information on CDD/CDF contamination of chlorobenzene products. The presence of CDDs/CDFs has been reported in tri-, penta-, and hexachlorobenzene. No CDDs/CDFs have been reported in mono- or dichlorobenzene. Conflicting data exist concerning the presence of CDDs/CDFs in trichlorobenzene. One study (Villanueva et al., 1974) detected no CDDs/CDFs in one sample of 1,2,4-TCBz at a DL of 0.1 μg/kg. Hutzinger and Fiedler (1991b) reported unpublished results of a study by Dr. Hans Hagenmaier showing CDD/CDF congener group concentrations ranging from 0.02 to 0.074 μg/kg in a sample of mixed TCBz. Because the TCBz examined by Hagenmaier contained about 2% hexachlorocyclohexane, it is reasonable to assume that it was produced by dehydrohalogenation of hexachlorocyclohexane (a manufacturing process not currently used in the United States).

In conclusion, although there is some evidence that CDD/CDFs may be present in chlorobenzene products, insufficient information is available to make quantitative estimates. Accordingly, they are considered to be unquantifiable.

8.4.3. Complex Plants

In the year 2000, two facilities with an SIC code for plastic materials, synthetic resins, and nonvulcanizable elastomers reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these facilities was 5.6 g, which EPA estimates is equal to 0.5 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

In the year 2000, four facilities with an SIC code for industrial organic chemicals not classified elsewhere reported dioxin releases under the EPA TRI program (U.S. EPA, 2008).

The sum of the air releases across these facilities was 153 g, which EPA estimates is equal to 2.2 g WHO_{98} TEQ_{DF}. No releases to other media were reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as supportive evidence that releases do occur.

The information presented in Dyke and Amendola (2007) was selected as the best basis for estimating CDD/CDF releases from facilities that produce combinations of chlorine and multiple chlorinated organic chemicals. The 10 complex chemical plants covered in this study are believed to represent most facilities of this type in the United States. Therefore, it was unnecessary to develop emission factors to estimate releases from untested facilities. Dyke and Amendola reported their release estimates in I-TEQs, but stated that WHO_{98} values were usually less than 20% different. Using the water congener profile, the WHO_{98} values were computed to be only 4% higher that the I-TEQs. On this basis the I-TEQs were assumed to be equivalent to the WHO_{98} TEQs for all releases. The Dyke and Amendola release estimates are specific to the year 2000. Because the chemical production rates and technologies used at these facilities have changed significantly, no release estimates could be made for 1987 and 1995.

Table 8-13 shows the amount of CDD/CDFs that are sent to off-site incinerators and landfills. The releases from incineration are included in the estimates presented for hazardous waste incinerators (see Section 3.2). The amounts sent to secure landfills (118 g I-TEQ in 2000) are not considered to be environmental releases.

The releases to all media from the complex chemical plants are presented in Table 8-13. The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes	Yes	Yes	Yes
Measured emission factors consistent or have understandable differences.	Yes	Yes	Yes	Yes
Emission factor tests represent units that are typical of the class.	Yes	Yes	Yes	Yes
Activity estimates based on source-specific surveys.	Yes	Yes	Yes	Yes
Conclusion (Q = Quantitative, P = Preliminary).	Q	Q	Q	Q

Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics
Air Releases
• 1987—Not available. • 1995—Not available. • 2000—5 g (WHO_{98} or I-TEQ).
Water Releases
• 1987—Not available. • 1995—Not available. • 2000—25 g (WHO_{98} or I-TEQ).
Solid Residue Releases
Landfarmed • 1987—Not available. • 1995—Not available. • 2000—1 g (WHO_{98} or I-TEQ).
Products
PVCs • 1987—Not quantifiable. • 1995—Not quantifiable. • 2000—Not quantifiable. **Pentachlorophenols** • 1987—Not quantifiable. • 1995—Not quantifiable. • 2000—Not quantifiable. **2,4-Dichlorophenoxy acetic acid (2,4-D)** • 1987—33 g WHO_{98} TEQ_{DF} (21 g I-TEQ_{DF}). • 1995—29 g WHO_{98} TEQ_{DF} (18 g I-TEQ_{DF}). • 2000—Not quantifiable. **Chlorobenzenes** • 1987—Not quantifiable. • 1995—Not quantifiable. • 2000—Not quantifiable.

8.5. MUNICIPAL WASTEWATER TREATMENT PLANTS

This section corresponds to Section 8.4.1 of the original report. Minor changes were made to the solid residue and product release estimates.

8.5.1. Air Releases

Releases associated with sewage sludge incineration are covered in Section 3.5.

8.5.2. Water Releases

No changes were made to the emission factors, activities, or release estimates. The CRWQCB data (memorandum dated March 21, 1996, from Lila Tang, California Regional Water Quality Control Board, to David Cleverly, U.S. EPA) were the only U.S. data that provided TEQ estimates for CDD/CDF levels in wastewaters from sewage treatment plants. Accordingly, the concentration from this study (0.27 pg WHO_{98} TEQ_{DF}/L [0.29 pg I-TEQ_{DF}/L]) was assumed to apply to all reference years. However, these data were from plants in the San Francisco area and cannot be considered to be representative of the 16,000-plus POTWs nationwide. Therefore, the emission factor was considered preliminary. Activity estimates were derived from EPA surveys as described in US EPA (2006) and are presented in the release summary below.

8.5.3. Solid Residue Releases

The large U.S. studies (U.S. EPA, 1996b, 2002d; Green et al., 1995; Cramer et al., 1995) were selected as the best basis for estimating emission factors. Because the mean I-TEQ_{DF} concentration values reported in the 1988/1989 sewage sludge survey (U.S. EPA, 1996b) and the 1995 survey (Green et al., 1995; Cramer et al., 1995) were very similar, the estimated amounts of TEQs that may have been present in sewage sludge and released to the environment in 1987 and 1995 were assumed to be the same. These values were estimated using the average of the mean concentration values (nondetects equal to DLs) reported by EPA (1996b) (50 ng I-TEQ_{DF}/kg) and by Green et al. (1995) and Cramer et al. (1995) (36.3 ng WHO_{98} TEQ_{DF}/kg [47.7 ng I-TEQ_{DF}/kg]). Therefore, the overall average mean emission factor for reference years 1987 and 1995 is 36.3 ng WHO_{98} TEQ_{DF}/kg (48.9 ng I-TEQ_{DF}/kg). The emission factor of 14 ng WHO_{98} TEQ_{DF}/kg (15 ng I-TEQ_{DF}/kg), as calculated from the 2001 survey (U.S. EPA, 2002d), appears to be the most reasonable TEQ emission factor estimate for reference year 2000 because this estimate is nationally weighted on the basis of wastewater flow rates of POTWs operating in the United States in 2001 (see Table 8-14—note that the values in this table were recalculated, resulting in minor decreases compared to the original document, which presented the data in Table 8-40).

No changes were made to the sludge activity results, which were presented in three categories: land applied (includes advanced treatment since this refers to composting, which is generally done in unlined containers), landfilled (includes sludge landfills, codisposal landfills, and surface disposal), and product (includes distribution/marketing and beneficial use). The summary table below presents the activities and releases for sludge, which is land applied or used in products. These are assumed to result in environmental releases. The landfilled sludges are not included in the summary because they are not considered to be environmental releases. The activity estimates for the landfilled sludge were 2.37 million dry MT in 1987, 1.10 million dry MT in 1995, and 0.90 million dry MT in 2000. The CDD/CDF amounts in the landfilled sludge were estimated as follows:

- 1987—86 g WHO TEQ_{DF} (120 g I-TEQ_{DF}/kg)
- 1995—40 g WHO TEQ_{DF} (54 g I-TEQ_{DF}/kg)
- 2000—13 g WHO TEQ_{DF} (14 g I-TEQ_{DF}/kg)

8.5.4. Products

The sewage sludge emission factors described above were also applied to the swage sludge used as products. No changes were made to the activity estimates. All of these values and the resulting release estimates are presented in the summary table below.

8.5.5. Releases

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Municipal Wastewater Treatment Plants				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.		Yes	Yes	Yes
Measured emission factors consistent or have understandable differences.		Yes	Yes	Yes
Emission factor tests represent units that are typical of the class.		No	Yes	Yes
Activity estimates based on source-specific surveys.		Yes	Yes	Yes
Conclusion (Q = Quantitative, P = Preliminary).		P	Q	Q

Municipal Wastewater Treatment Plants

Air Releases

None.

Water Releases

Emission Factors

- 1987—0.27 pg WHO TEQ_{DF}/L (0.29 pg I-TEQ_{DF}/L) (Preliminary).
- 1995—0.27 pg WHO TEQ_{DF}/L (0.29 pg I-TEQ_{DF}/L) (Preliminary).
- 2000—0.27 pg WHO TEQ_{DF}/L (0.29 pg I-TEQ_{DF}/L) (Preliminary).

Activity Levels

- 1987—47.8 trillion L.
- 1995—44.5 trillion L.
- 2000—54.0 trillion L.

Releases

- 1987—13 g WHO TEQ_{DF}/yr (14 g I-TEQ_{DF}/yr) (Preliminary).
- 1995—12 g WHO TEQ_{DF}/yr (13 g I-TEQ_{DF}/yr) (Preliminary).
- 2000—15 g WHO TEQ_{DF}/yr (16 g I-TEQ_{DF}/yr) (Preliminary).

Solid Residue Releases

Emission Factors

- 1987—36 ng WHO TEQ_{DF}/kg (49 ng I-TEQ_{DF}/kg).
- 1995—36 ng WHO TEQ_{DF}/kg (49 ng I-TEQ_{DF}/kg).
- 2000—14 ng WHO TEQ_{DF}/kg (15 ng I-TEQ_{DF}/kg).

Activity Levels

Land Applied

- 1987—1.71 million dry MT/yr.
- 1995—3.20 million dry MT/yr.
- 2000—3.60 million dry MT/yr.

Releases

Land Applied

- 1987—62 g WHO TEQ_{DF} (84 g I-TEQ_{DF}/kg).
- 1995—120 g WHO TEQ_{DF} (160 g I-TEQ_{DF}/kg).
- 2000—50 g WHO TEQ_{DF} (54 g I-TEQ_{DF}/kg).

Municipal Wastewater Treatment Plants (continued)
Products
Emission Factors • 1987—36 ng WHO TEQ_{DF}/kg (49 ng I-TEQ_{DF}/kg). • 1995—36 ng WHO TEQ_{DF}/kg (49 ng I-TEQ_{DF}/kg). • 2000—14 ng WHO TEQ_{DF}/kg (15 ng I-TEQ_{DF}/kg).
Activity Levels • 1987—0.07 MMT. • 1995—0.50 MMT. • 2000—0.50 MMT.
Releases • 1987—3 g WHO TEQ_{DF} (3 g I-TEQ_{DF}/kg). • 1995—18 g WHO TEQ_{DF} (24 g I-TEQ_{DF}/kg). • 2000—7 g WHO TEQ_{DF} (8 g I-TEQ_{DF}/kg).

8.6. DRINKING WATER TREATMENT PLANTS

This section corresponds to Section 8.4.2 in the original report. As discussed in the original report, there is no evidence that releases of CDD/CDFs occur from drinking water treatment plants. No changes were made to this conclusion.

8.7. SOAPS AND DETERGENTS

This section corresponds to Section 8.4.3 in the original report. As discussed in the original report, there is some evidence that soaps and detergents may be a source of CDD/CDFs, but the data were judged inadequate for making quantitative estimates.

Soaps and Detergents
Releases
Not quantifiable.

8.8. TEXTILE MANUFACTURING AND DRY CLEANING

This section corresponds to Section 8.4.4 in the original report. As discussed in the original report, there is some evidence that textiles manufacturing and dry cleaning may be sources of CDD/CDFs, but the data were judged inadequate for making quantitative estimates.

Textiles Manufacturing and Dry Cleaning
Releases
Not quantifiable.

8.9. DYES, PIGMENTS, AND PRINTING INKS

This section corresponds to Section 8.3.6 in the original report. As discussed in the original report, very little chloranil has been produced in the United States since the 1980s, so production releases during the reference years are probably negligible. EPA (2006) used concentration and import data to estimate that chloranil imports contained 64 g I-TEQ in 1987, 0.4 g I-TEQ in 1995, and 1.2 g I-TEQ in 2000. It is unknown if releases occurred from these products.

Chloranil Imports
Releases
Not quantifiable.

Similarly, some evidence exists that phthalocyanine dyes and printing inks may be a source of CDD/CDFs, but the data were judged inadequate for making quantitative estimates.

Phthalocyanine Dyes and Printing Inks
Releases
Not quantifiable.

8.10. OTHER ALIPHATIC CHLORINE COMPOUNDS

This section corresponds to Section 8.3.5 in the original report. As discussed in the original report, there is no strong evidence that CDD/CDFs are present in these compounds.

8.11. RESIDENTIAL SEPTIC SYSTEMS

This is a new section. Because CDD/CDFs have been measured in discharges from municipal wastewater treatment systems, they may also be released from residential septic systems. No information was found on measured CDD/CDF levels in the sewage entering these systems. However, preliminary estimates can be made as discussed below.

8.11.1. Process Description

Most residential septic systems consist of a septic tank and drainage field or dry well. The household waste flows by gravity into the septic tank where biological digestion occurs and solids settle out. The overflow goes into the drainage field or dry well where it slowly percolates into the ground.

8.11.2. Regulations

None specific to dioxins.

8.11.3. Emission Factor

No measurements were found on the amount of CDD/CDF excreted by people. However studies have been done with dairy cattle involving measurements of dioxins in their feed, milk, feces, and urine under carefully controlled settings (Winters et al., 2000; Lorber et al., 2000; McLachlan et al., 1990). These studies found that 50% to 100% of both TEQs and individual congeners in the feed were recovered in the milk and feces. For purposes of a preliminary estimate, it is assumed here that 100% of the dioxin TEQs ingested by people are excreted in the feces. Clearly this is an overestimate particularly for lactating mothers. For the general population, adult daily intakes are estimated to average 43 pg WHO_{98} TEQ_{DF} for CDD/CDFs and 23 pg WHO_{98} TEQ_{PCB} for PCBs (U.S. EPA, 2004). It is assumed that 30 pg WHO_{98} TEQ_{DF}/day represents a whole population average (children plus adults) for the CDD/CDFs. Assuming that two thirds of an individual's excretion occurs at their residence, 20 pg $WHO_{98}TEQ_{DF}$/day is discharged to the septic system. It is also assumed that no TEQ degradation or formation occurs in the septic system.

Septic systems are designed to trap the solid components of sewage in a septic tank. The tank is periodically pumped, and the contents are discharged to a municipal wastewater treatment system (these releases are covered in Section 8.5). Many of the smaller particles and oily components will flow into the drainage field. The fraction CDD/CDFs released to the drainage field will depend largely on the solids trapping efficiency of the system, which depends on variables such as tank size, flow rates, and pumping frequency. For the purposes of a preliminary estimate, this is assumed to be 50%. Thus, the overall emission factor is assumed to be 10 pg WHO_{98} TEQ_{DF}/day-person and would be applicable to all reference years. Considering the lack of direct feces measurements and multiple assumptions required for this estimate, it is given a preliminary confidence rating.

8.11.4. Activity

Septic systems serve 25% of the U.S. population (U.S. EPA, 2005). The total U.S. population is estimated to be 242 million in 1987, 263 million in 1995, and 300 million in 2000 (U.S. DOC, 2000). Multiplying by 25%, the activity for each reference year is 61 million in 1987, 66 million in 1995, and 75 million in 2000.

8.11.5. Releases

The releases from septic systems will occur via the liquid effluent that drains into the soil. It is included with the solid residues because the release is to land.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Residential Septic Systems				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.			No	
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.				
Activity estimates based on source-specific surveys.			Yes	
Conclusion (Q = Quantitative, P = Preliminary).			P	

Residential Septic Systems
Air Releases
None.
Water Releases
None.
Solid Residue Releases
Emission Factors • 1987—10 pg WHO_{98} TEQ_{DF}/day-person (Preliminary). • 1995—10 pg WHO_{98} TEQ_{DF}/day-person (Preliminary). • 2000—10 pg WHO_{98} TEQ_{DF}/day-person (Preliminary).
Activity Levels • 1987—61 million people. • 1995—66 million people. • 2000—75 million people.
Releases • 1987—0.2 g WHO_{98} TEQ_{DF} (Preliminary). • 1995—0.2 g WHO_{98} TEQ_{DF} (Preliminary). • 2000—0.3 g WHO_{98} TEQ_{DF} (Preliminary).

Table 8-1. CDD/CDF concentrations (μg/kg) in graphite electrode sludge from chlorine production

Congener/congener group	Sludge 1	Sludge 2	Sludge 3	Sludge 4
2,3,7,8-TCDD	ND (0.006)	ND (0.009)	ND (0.009)	ND
1,2,3,7,8-PeCDD	ND (0.007)	ND (0.009)	ND (0.009)	ND (0.033)
1,2,3,4,7,8-HxCDD	ND (0.018)	ND (0.026)	ND (0.029)	ND (0.49)
1,2,3,6,7,8-HxCDD	ND (0.012)	ND (0.016)	ND (0.019)	ND (0.053)
1,2,3,7,8,9-HxCDD	ND (0.016)	ND (0.022)	ND (0.025)	ND (1.2)
1,2,3,4,6,7,8-HpCDD	0.095	0.21	0.25	0.055
OCDD	0.92	2	2.2	0.65
2,3,7,8-TCDF	26	56	57	52
1,2,3,7,8-PeCDF	25	55	56	55
2,3,4,7,8-PeCDF	12	25	24	27
1,2,3,4,7,8-HxCDF	32	71	73	44
1,2,3,6,7,8-HxCDF	7	16	15	12
1,2,3,7,8,9-HxCDF	1.3	2.8	2.6	1.7
2,3,4,6,7,8-HxCDF	0.87	1.9	2	1.3
1,2,3,4,6,7,8-HpCDF	9.1	19	19	15
1,2,3,4,7,8,9-HpCDF	8.1	19	20	14
OCDF	31	76	71	81
Total 2,3,7,8-CDD[a]	1.02	2.21	2.45	0.7
Total 2,3,7,8-CDF[a]	152.37	341.7	339.6	303
Total I-TEQ_{DF}[a]	14.2	30.5	30.2	27.7
Total WHO_{98} TEQ_{DF}[a]	14.1	30.4	30.2	27.6
Total TCDD	ND (0.006)	ND (0.009)	ND (0.009)	--
Total PeCDD	ND (0.070)	ND (0.009)	ND (0.009)	--
Total HxCDD	ND (0.046)	ND (0.064)	ND (0.074)	--
Total HpCDD	0.22	0.48	0.56	--
Total OCDD	0.92	2	2.2	0.65
Total TCDF	64	150	140	--
Total PeCDF	75	240	240	--
Total HxCDF	68	140	140	--
Total HpCDF	24	53	54	--
Total OCDF	31	76	71	81
Total CDD/CDF[a]	263.14	661.48	647.76	--

[a]Calculated assuming nondetect values were zero.
ND = Not detected (value in parenthesis is the reported detection limit).
-- = No information given.

Sources: Rappe et al. (1991); Rappe (1993).

Table 8-2. Releases of dioxin-like compounds in wastewater discharges from chlor-alkali manufacturing facilities to surface water in 2000

Congener	Occidental Chemical Corporation						PPG Industries	Total
	Battleground, TX	Deer Park, TX	Delaware City, DE	Hahnville, LA	Mobile, AL	Muscle Shoals, AL	Natrium, WV	
2,3,7,8 TCDD	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
1,2,3,7,8 PeCDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,2,3,4,7,8 HxCDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,2,3,6,7,8 HxCDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,2,3,7,8,9 HxCDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1,2,3,4,6,7,8 HpCDD	0.00	0.08	0.00	0.01	0.00	0.00	0.22	0.31
OCDD	0.48	21.50	4.09e!03	0.10	1.15e!03	1.13e!09	3.13	25.22
2,3,7,8 TCDF	0.00	0.63	1.02e!03	0.19	2.88e!04	3.94e!08	0.06	0.89
1,2,3,7,8 PeCDF	0.00	1.20	0.00	0.90	0.00	1.33e!07	0.06	2.16
2,3,4,7,8 PeCDF	0.00	0.21	0.00	0.85	0.00	7.99e!08	0.33	1.39
1,2,3,4,7,8 HxCDF	0.00	2.11	0.00	2.96	0.00	1.85e!07	0.11	5.18
1,2,3,6,7,8 HxCDF	0.00	0.38	0.00	1.18	0.00	9.76e!08	0.00	1.56
1,2,3,7,8,9 HxCDF	0.00	2.03e!03	0.00	0.63	0.00	2.29e!08	0.00	0.63
2,3,4,6,7,8 HxCDF	0.00	0.00	0.00	0.60	0.00	3.28e!08	0.00	0.60
1,2,3,4,6,7,8 HpCDF	0.00	0.59	2.31e!03	4.47	6.49e!04	1.32e!07	0.15	5.22
1,2,3,4,7,8,9 HpCDF	0.00	5.66e!03	0.00	0.69	0.00	6.30e!08	0.00	0.69
OCDF	0.00	4.88	0.00	1.75	0.00	1.34e!07	0.66	7.29
Total I-TEQ	4.83e!04	0.53	1.29e!04	1.08	3.64e!05	8.65e!08	0.19	1.80
Total WHO_{98} TEQ_{DF}	4.83e!05	0.51	1.26e!04	1.08	3.54e!05	8.63e!08	0.19	1.59

Source: CCC (2004).

Table 8-3. Congener-specific and TEQ annual releases to air (g/year) from a chlor-alkali facility in 2000

Congener	PPG Industries Natrium, WV
2,3,7,8-TCDD	0.003
1,2,3,7,8-PeCDD	0.000
1,2,3,4,7,8-HxCDD	0.000
1,2,3,6,7,8-HxCDD	0.002
1,2,3,7,8,9-HxCDD	0.002
1,2,3,4,6,7,8-HpCDD	0.087
OCDD	0.208
2,3,7,8-TCDF	0.044
1,2,3,7,8-PeCDF	0.003
2,3,4,7,8-PeCDF	0.030
1,2,3,4,7,8-HxCDF	0.044
1,2,3,6,7,8-HxCDF	0.006
1,2,3,7,8,9-HxCDF	0.006
2,3,4,6,7,8-HxCDF	0.022
1,2,3,4,6,7,8-HpCDD	0.142
1,2,3,4,7,8,9-HpCDD	0.039
OCDF	0.064
Total I-TEQ_{DF}	0.034
Total WHO_{98} TEQ_{DF}	0.033

Source: Chlorine Chemistry Council (2004).

Table 8-4. Annual releases in 2000 from stand-alone chlor-alkali plants (g I-TEQ/year)

Plant/Location	Chemicals	On-site				Off-site transfers[a]		
		Air	Water	Landfill	Landfarm	Landfill	Incineration	Well Inj
Occidental—Mobile, AL	Cl2 (membrane-cell), caustic potash, sodium silicate		3.60×10^{-5}			0.83		
Confidence Rating			H/H			H/H		
Occidental—Battleground, TX	Cl2 (diaphragm-cell), NaOH		4.80×10^{-4}					
Confidence Rating			H/H					
Occidental—Deer Park, TX (CA)	Cl2 (mercury/diaphragm-cell), NaOH		0.54			0.38		
Confidence Rating			H/H			R/H		
Occidental—Delaware City, DE	Cl2 (mercury-cell), NaOH, caustic potash,		1.30×10^{-4}			0.81	3.50×10^{-6}	
Confidence Rating			R/H			H/H	H/H	
Occidental—Hahnville (Taft), LA	Cl2 (mercury/diaphragm-cell), NaOH, sulfur		1.08			0.2	9.60×10^{-9}	0.04
Confidence Rating			H/H			H/H	H/H	R/H
Occidental—Muscle Shoals, AL	Cl2 (mercury-cell) and caustic potash		8.70×10^{-8}			0.38		
Confidence Rating			H/H			H/H		
PPG Industries—Natrium, WV	Cl2 (mercury/diaphragm-cell cell), NaOH	0.034	0.193			0.085		
Confidence Rating		R/H	R/R			H/H		
Total		0.03	1.81	0.0	0.0	2.69	0.0	0.04

[a]The off-site transfers represent the amount going to off-site facilities and not the amount released to the environment.
H = High.
R = Reasonable.
Source: Dyke and Amendola, 2007.

Table 8-5. Reported CDD/CDF concentrations (μg/kg) in wastes from polyvinyl chloride (PVC) manufacture

Congener/congener group	F024 waste	K019 waste	K020 waste
2,3,7,8-TCDD	0.37	260	0.06
1,2,3,7,8-PeCDD	0.14	890	0.05
1,2,3,4,7,8-HxCDD	0.3	260	0.08
1,2,3,6,7,8-HxCDD	0.14	330	0.06
1,2,3,7,8,9-HxCDD	0.11	620	0.07
1,2,3,4,6,7,8-HpCDD	4.2	920	0.89
OCDD	15	1,060	3
2,3,7,8-TCDF	0.91	680	0.44
1,2,3,7,8-PeCDF	9.5	975	1.8
2,3,4,7,8-PeCDF	1.6	1,050	0.58
1,2,3,4,7,8-HxCDF	110	10,100	11
1,2,3,6,7,8-HxCDF	24	9,760	2.4
1,2,3,7,8,9-HxCDF	9.5	21,800	1.3
2,3,4,6,7,8-HxCDF	3.1	930	0.89
1,2,3,4,6,7,8-HpCDF	250	13,400	38
1,2,3,4,7,8,9-HpCDF	51	1,340	6
OCDF	390	43,500	650
Total 2,3,7,8-CDD	20.3	4,340	4.21
Total 2,3,7,8-CDF	849.6	103,535	712.4
Total I-TEQ_{DF}	20	5,928	3.2
Total WHO_{98} TEQ_{DF}	19.7	6,333	2.6
Total TCDD	3.1	1,230	1.9
Total PeCDD	3.6	3,540	1.7
Total HxCDD	1.3	3,950	[a]
Total HpCDD	5	1,270	1.7
Total OCDD	15	1,060	3
Total TCDF	15	20,600	6
Total PeCDF	65	45,300	11
Total HxCDF	300	63,700	27
Total HpCDF	450	16,600	58
Total OCDF	390	43,500	650
Total CDD/CDF	1,248	200,750	760.3

[a]Congener group concentration reported in source is not consistent with reported congener concentrations.

Source: Stringer et al. (1995).

Table 8-6. CDD/CDF concentrations in products from U.S. EDC/VCM/PVC manufacturers

Congener/congener group	Suspension and mass PVC resins			Dispersion PVC resins			EDC sold as product[d]		
	No. detects/ samples[a]	Range[b] (ng/kg) Min.	Range[b] (ng/kg) Max.	No. of detects/ samples	Range[c] (ng/kg) Min.	Range[c] (ng/kg) Max.	No. detects/ samples	Range[e] (ng/kg) Min.	Range[e] (ng/kg) Max.
2,3,7,8-TCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,7,8-PeCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,4,7,8-HxCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,6,7,8-HxCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,7,8,9-HxCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,4,6,7,8-HpCDD	1/22	ND	0.64	1/6	ND	0.8	0/5	ND	ND
OCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
2,3,7,8-TCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,7,8-PeCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
2,3,4,7,8-PeCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,4,7,8-HxCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,6,7,8-HxCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
1,2,3,7,8,9-HxCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
2,3,4,6,7,8-HxCDF	1/22	ND	0.37	0/6	ND	ND	0/5	ND	ND
1,2,3,4,6,7,8-HpCDF	0/22	ND	ND	0/6	ND	ND	1/5	ND	1.1
1,2,3,4,7,8,9-HpCDF	0/22	ND	ND	0/6	ND	ND	1/5	ND	0.4
OCDF	0/22	ND	ND	2/6	ND	0.38	1/5	ND	11
Mean I-TEQ$_{DF}$ (nondetect = 0)		0.002	0.7		0.001	0.4		0.001	0.21
Mean I-TEQ$_{DF}$ (nondetect = ½ DL)									

Table 8-6. CDD/CDF concentrations in products from U.S. EDC/VCM/PVC manufacturers (continued)

Congener/congener group	Suspension and mass PVC resins			Dispersion PVC resins			EDC sold as product[d]		
	No. detects/ samples[a]	Range[b] (ng/kg)		No. of detects/ samples	Range[c] (ng/kg)		No. detects/ samples	Range[e] (ng/kg)	
		Min.	Max.		Min.	Max.		Min.	Max.
Total TCDD	0/22	ND	ND	1/6	ND	0.24	0/5	ND	ND
Total PeCDD	0/22	ND	ND	1/6	ND	0.32	0/5	ND	ND
Total HxCDD	0/22	ND	ND	5/6	ND	0.97	0/5	ND	ND
Total HpCDD	1/22	ND	0.64	1/6	ND	1.3	0/5	ND	ND
Total OCDD	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
Total TCDF	0/22	ND	ND	0/6	ND	ND	0/5	ND	ND
Total PeCDF	0/22	ND	ND	1/6	ND	0.3	0/5	ND	ND
Total HxCDF	1/22	ND	0.37	0/6	ND	ND	0/5	ND	ND
Total HpCDF	0/22	ND	ND	0/6	ND	ND	1/5	ND	2.02
Total OCDF	0/22	ND	ND	2/6	ND	0.38	1/5	ND	11

[a]Two of these 22 samples were duplicate samples from two sites. The results were averaged and treated as one sample for each site.
[b]Detection limits (DLs) for individual samples were less than 2 ng/kg for all congeners and congener groups except OCDD and OCDF, which had DLs less than 6 ng/kg.
[c]DLs for individual samples were less than 2 ng/kg for all congeners and congener groups except OCDD and OCDF, which had DLs less than 4 ng/kg.
[d]"Sales" EDC is defined as EDC sold commercially for non-VCM uses or exported from the United States.
[e]DLs were less than 1 ng/kg for all congeners in all samples.
DL = Detection limit.
EDC = Ethylene dichloride.
ND = Not detected.
PVC = Polyvinyl chloride.
VCM = Vinyl chloride monomer.

Source: The Vinyl Institute (1998).

Table 8-7. Annual releases in 2000 from stand-alone vinyl chloride plants (g I-TEQ/year)

Plant/Location	Chemicals	On-site				Off-site Transfers[a]	
		Air	Water	Landfill	Landfarm	Landfill	Incineration
Occidental—Deer Park, TX	VCM	0.581	0.031			0.474	22.2
Confidence Rating		H/H	H/H			H/H	H/H
Occidental—LaPorte, TX	VCM	0.039	0.0064			5.1	44.4
Confidence Rating		H/H	H/H			H/H	H/H
Total		0.62	0.04			5.57	66.60

[a]The off-site transfers represent the amount going to off-site facilities and not the amount released to the environment.
H = High Confidence.

Source: Dyke and Amendola, 2007.

Table 8-8. CDD/CDF concentrations (mg/kg) in mono-through tetrachlorophenols

Congener/ congener group	2-CP[a]	2,4-DCP[a]	2,6-DCP[a]	2,4,5-TrCP (Na salt)[a]	2,4,5-TrCP[a]	2,4,6-TrCP[a]	2,4,6-TrCP (Na salt)[b]	2,3,4,6-TeCP[a]	2,3,4,6-TeCP (Na salt)[b]
Total TCDD	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02) to 14	ND (0.02) to 6.5	ND (0.02) to 49	<0.02	ND (0.02)	0.7
Total PeCDD	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02) to 1.5	ND (0.02)	<0.03	ND (0.02)	5.2
Total HxCDD	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	<0.03	ND (0.02) to 15	9.5
Total HpCDD	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	<0.1	ND (0.02) to 5.1	5.6
Total OCDD	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	ND (0.02)	<0.1	ND (0.02) to 0.17	0.7
Total TCDF	+	ND	ND	ND	ND	+	1.5	+	0.5
Total PeCDF	ND	ND	ND	ND	ND	+	17.5	+	10
Total HxCDF	ND	ND	ND	ND	ND	+	36	+	70
Total HpCDF	ND	ND	ND	ND	ND	ND	4.8	+	70
Total OCDF	ND	ND	ND	ND	ND	ND	--	+	10
TOTAL	--	--	--	--	--	--	--	--	--

[a]Source: Firestone et al. (1972); because of poor recoveries, the authors stated that actual CDD/CDF levels may have been considerably higher than those reported.
[b]Sources: Rappe and Marklund (1978); Rappe et al. (1978); common Scandinavian commercial chlorophenols.
ND = Not detected (value in parenthesis is the detection limit, if reported).
+ = Detected but not quantified.
-- = No information given.

Table 8-9. Summary of specific dioxin-containing wastes that must comply with land disposal restrictions[a]

EPA hazardous waste number	Waste description	Land disposal restriction effective date	Regulated waste constituent
F020	Wastes (except wastewater and spent carbon from HCl 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
F021	Wastes (except wastewater and spent carbon from HCl 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
F022	Wastes (except wastewater and spent carbon from HCl 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
F023	Wastes (except wastewater and spent carbon from HCl 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
F026	Wastes (except wastewater and spent carbon from HCl 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

Table 8-9. Summary of specific dioxin containing wastes that must comply with land disposal restrictions[a] (continued)			
EPA hazardous waste number	**Waste description**	**Land disposal restriction effective date**	**Regulated waste constituent**
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
F028	Residues resulting from the incineration or thermal treatment of soil contaminated with EPA Hazardous Wastes No. F020BF023, F026, and F027.	November 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs
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 (nonwastewater)	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs
K043	2,6-Dichlorophenol waste from the production of 2,4-D.	June 8, 1989	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs
K099	Untreated wastewater from the production of 2,4-D.	August 8, 1988	TCDDs PeCDDs HxCDDs TCDFs PeCDFs HxCDFs

[a]For wastewater, the treatment standard for all regulated waste constituents—except for PeCDFs—is 0.063 μg/L; the standard for PeCDFs is 0.035 μg/L. For nonwastewater, the treatment standard for all regulated waste constituents is 1 μg/kg. Treatment standards are based on incineration to 99.9999% destruction and removal efficiency.

Source: 40 CFR 268.

Table 8-10. CDD/CDF concentrations (historical and current) (µg/kg) in technical-grade pentachlorophenol (PCP) products

Congener/ congener group	1973[a]	1978[b]	1979[c]	1984[d]	1985[e]	1986[e]	1987[f]	1987[g]	1985B88[h]	1991[i]	1988B99[e]	1988B99[j]	Unknown[k]
2,3,7,8-TCDD	--	--	--	ND (10)	ND (0.05)	ND (0.05)	ND (0.03)	ND (0.05)	ND (0.05)	ND	--	ND (0.5)	ND (10)
1,2,3,7,8-PeCDD	--	--	--	ND (10)	ND (1)	ND (1)	1	2	ND (1)	ND	--	--	ND (10)
1,2,3,4,7,8-HxCDD	--	--	--	-	6	8	ND (1)	ND (1)	8	--	--	--	ND (10)
1,2,3,6,7,8-HxCDD	--	--	--	2,200	2,565	1,532	831	1,480	600	--	--	--	860
1,2,3,7,8,9-HxCDD	--	--	--	100	44	28	28	53	13	--	--	--	20
1,2,3,4,6,7,8-HpCDD	--	--	--	100,000	210,000	106,000	78,000	99,900	89,000	--	--	--	36,400
OCDD	--	--	--	610,000	1,475,000	930,000	733,000	790,000	2,723,000	1,100,000	--	--	296,810
2,3,7,8-TCDF	--	--	--	ND (10)	ND (0.5)	ND (0.5)	ND (0.1)	ND (0.1)	ND (0.5)	ND	--	--	ND (10)
1,2,3,7,8-PeCDF	--	--	--	--	ND (1)	ND (1)	0.5	0.2	ND (1)	ND	--	--	ND (10)
2,3,4,7,8-PeCDF	--	--	--	--	ND (1)	ND (1)	1.5	0.9	ND (1)	ND	--	--	ND (10)
1,2,3,4,7,8-HxCDF	--	--	--	--	49	34	125	163	67	--	--	--	200
1,2,3,6,7,8-HxCDF	--	--	--	--	5	4	ND (1)	ND (1)	2	--	--	--	ND (20)
1,2,3,7,8,9-HxCDF	--	--	--	--	5	ND (1)	32	146	ND (1)	--	--	--	ND (20)
2,3,4,6,7,8-HxCDF	--	--	--	--	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	--	--	--	ND (20)
1,2,3,4,6,7,8-HpCDF	--	--	--	--	34,000	29,000	11,280	19,940	22,000	--	--	--	2,000
1,2,3,4,7,8,9-HpCDF	--	--	--	--	4,100	6,200	637	980	3,400	--	--	--	140
OCDF	--	130,000	--	130,000	222,000	233,000	118,000	137,000	237,000	170,000	--	--	19,940
Total 2,3,7,8-CDD[1]	--	--	--	712,300	1,687,615	1,037,568	811,860	891,435	2,812,621	1,100,000	--	--	334,090
Total 2,3,7,8-CDF[1]	--	--	--	130,000	260,159	268,238	130,076	158,230	262,469	170,000	--	--	22,280
Total I-TEQ_{DF}[1]	--	--	--	1,970	4,445	2,735	1,853	2,321	4,173	∃1,270	--	--	810
Total WHO_{98} TEQ_{DF}[1]	--	--	--	1,304	2,918	1,689	1,088	1,488	1,509	>127	--	--	525
Total TCDD	ND (20)	--	--	ND (10)	ND	ND	1.9	0.4	ND	ND (10)	ND (1)	ND	--
Total PeCDD	ND (30)	--	--	ND (10)	ND	ND	6.5	15.2	ND	ND (10)	ND (10)	3	--
Total HxCDD	5,500	--	10,100	4,500	4,694	2,925	1,700	3,300	912	8,900	1,440	1,490	--
Total HpCDD	98,000	--	296,000	135,000	283,000	134,000	154,000	198,000	117,000	130,000	55,560	48,430	--
Total OCDD	220,000	--	1,386,000	610,000	1,475,000	930,000	733,000	790,000	2,723,000	1,100,000	--	191,700	--
Total TCDF	40	900	--	ND (10)	6	ND	0.8	0.4	ND	ND (10)	ND (10)	48	--
Total PeCDF	250	4,000	1,400	--	10	3	141	343	200	ND (10)	ND (10)	520	--
Total HxCDF	22,000	32,000	9,900	--	1,982	1,407	4,300	13,900	1,486	14,000	3,070	13,650	--
Total HpCDF	150,000	120,000	88,000	62,000	125,000	146,000	74,000	127,000	99,000	36,000	36,530	76,090	--
Total OCDF	160,000	130,000	43,000	130,000	222,000	233,000	118,000	137,000	237,000	170,000	--	136,310	--
Total CDD/CDF[l]	655,790	286,900	1,834,400	941,500	2,111,692	1,447,335	1,085,150	1,269,559	3,178,598	1,458,900	960,000	468,241	--

Table 8-10. CDD/CDF concentrations (historical and current) (µg/kg) in technical-grade pentachlorophenol (PCP) products (continued)

[a]Source: Buser and Bosshardt (1976); mean of 10 samples of Ahigh@ CDD/CDF-content PCP received from Swiss commercial sources in 1973.
[b]Source: Rappe et al. (1978); sample of U.S. origin, Apresumably prepared by alkaline hydrolysis of hexachlorobenzene.@
[c]Source: NTP (1989); composite of technical-grade materials produced in 1979 by Monsanto Industrial Chemical Co. (St. Louis, MO), Reichhold Chemicals, Inc. (White Plains, NY), and Vulcan Materials Co. (Birmingham, AL).
[d]Source: Cull et al. (1984); mean of four Arecent@ production batches from each of two manufacturers of technical PCP using three different analytical methods; analysis of variance (ANOVA) showed no statistically significant difference in CDD/CDF concentrations between the eight samples (samples obtained in the United Kingdom).
[e]Source: Letter dated February 7, 1997, from John Wilkinson, Pentachlorophenol Task Force, to Matthew Lorber, U.S. EPA; average of monthly batch samples for the period January 1987 to August 1996.
[f]Source: Hagenmaier and Brunner (1987); sample of Witophen P (Dynamit Nobel-Lot no. 7777) (obtained in Germany).
[g]Source: Hagenmaier and Brunner (1987); sample of PCP produced by Rhone Poulenc (obtained in Germany).
[h]Source: Letter dated February 7, 1997, from John Wilkinson, Pentachlorophenol Task Force, to Matthew Lorber, U.S. EPA; samples of Apenta@ manufactured in 1985, 1986, and 1988.
[i]Source: Harrad et al. (1991); PCP-based herbicide formulation from the New York State Department of Environmental Conservation.
[j]Source: Letter dated March 5, 1997, from Thomas Mitchell, KMG-Bernuth, to Matthew Lorber, U.S. EPA; average of monthly batch samples for the period February 1987 to December 1996 (excluding the following months, for which data were not available: February 1993, January 1992, December 1991, September 1991, December 1988, and September 1988).
[k]Source: Schecter et al. (1997); sample found stored in a barn in Vermont.
[l]Calculated assuming nondetects were zero.
ND = Not detected (value in parenthesis is the detection limit).
-- = No information given.

Table 8-11. Historical CDD/CDF concentrations (µg/kg) in pentachlorophenol-Na (PCP-Na)

Congener/congener group	1969[a]	1973[b]	1973[c]	1987[d]	1987[e]	1992[f]	1980s[g]
2,3,7,8-TCDD	--	--	--	0.23	0.51	0.076	ND (1.4)
1,2,3,7,8-PeCDD	--	--	--	18.2	3.2	18.7	28.3
1,2,3,4,7,8-HxCDD	--	--	--	28.3	13.3	96	ND (6.1)
1,2,3,6,7,8-HxCDD	--	--	--	2,034	53	4,410	4,050
1,2,3,7,8,9-HxCDD	--	--	--	282	19	328	ND (1.4)
1,2,3,4,6,7,8-HpCDD	--	--	--	9,100	3,800	175,400	33,800
OCDD	3,600	--	--	41,600	32,400	879,000	81,000
2,3,7,8-TCDF	--	--	--	1.8	0.79	ND (1)	149
1,2,3,7,8-PeCDF	--	--	--	8.2	1.9	ND (4)	319
2,3,4,7,8-PeCDF	--	--	--	6.6	1.1	ND (4)	324
1,2,3,4,7,8-HxCDF	--	--	--	48	4.6	27.6	ND (2.8)
1,2,3,6,7,8-HxCDF	--	--	--	69	1.3	21.9	225
1,2,3,7,8,9-HxCDF	--	--	--	ND (1)	1.3	9.8	480
2,3,4,6,7,8-HxCDF	--	--	--	87	4.6	103	ND (385)
1,2,3,4,6,7,8-HpCDF	--	--	--	699	197	9,650	6,190
1,2,3,4,7,8,9-HpCDF	--	--	--	675	36	2,080	154
OCDF	--	--	--	37,200	4,250	114,600	36,000
Total 2,3,7,8-CDD[h]	--	--	--	53,062.7	36,289	1,059,252.8	118,878.3
Total 2,3,7,8-CDF[h]	--	--	--	38,794.6	4,498.6	126,492.3	43,841
Total I-TEQ_{DF}[h]	--	--	--	452	89.5	3,374	1,201
Total WHO_{98} TEQ_{DF}[h]	--	--	--	390	58.1	2,489	1,110
Total TCDD	--	140	50	27	52	3.6	1.9
Total PeCDD	--	40	ND (30)	213	31	142.7	140
Total HxCDD	17,000	140	3,400	3,900	230	9,694	14,000
Total HpCDD	9,600	1,600	38,000	18,500	5,800	260,200	100,000
Total OCDD	3,600	4,000	110,000	41,600	32,400	879,000	81,000
Total TCDF	--	ND (20)	ND (20)	82	12	10.1	1,200
Total PeCDF	--	60	40	137	27	88.4	6,400
Total HxCDF	--	1,400	11,000	3,000	90	9,082.3	49,000
Total HpCDF	--	4,300	47,000	13,200	860	75,930	91,000
Total OCDF	--	4,300	26,500	37,200	4,250	114,600	36,000
Total CDD/CDF[h]	30,200	15,980	235,990	117,859	43,752	1,348,751	378,742

[a]Source: Firestone et al. (1972); mean of two samples of PCP-Na obtained in the United States between 1967 and 1969.

[b]Source: Buser and Bosshardt (1976); mean of five samples of Alow@ CDD/CDF-content PCP-Na received from Swiss commercial sources.

[c]Source: Buser and Bosshardt (1976); sample of Ahigh@ CDD/CDF-content PCP-Na received from a Swiss commercial source.

Table 8-11. Historical CDD/CDF concentrations (µg/kg) in pentachlorophenol Na (PCP Na) (continued)

[d]Source: Hagenmaier and Brunner (1987); sample of Dowicide-G purchased from Fluka; sample obtained in Germany.
[e]Source: Hagenmaier and Brunner (1987); sample of Preventol PN (Bayer AG); sample obtained in Germany.
[f]Source: Santl et al. (1994); 1992 sample of PCP-Na from Prolabo, France.
[g]Source: Palmer et al. (1988); sample of a PCP-Na formulation collected from a closed sawmill in California in the late 1980s.
[h]Calculated assuming nondetect values were zero.
ND = Not detected (value in parenthesis is the detection limit).
-- = No information given.

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Table 8-12. CDD/CDF concentrations (µg/kg) in chlorobenzenes

Congener/ congener group	MCBz[a]	1,2-DCBz (for synthesis)[a]	1,2,4-TrCBz (Apure@)[b]	Mixed TrCBz (47%)[a]	1,2,4,5-TCBz (99%)[a]	PeCBz (98%)[a]	HCBz (97%)[a]	HCBz[b]
Total TCDD	ND (0.02)	0.3	ND (0.1)	0.027	ND (0.02)	ND (0.02)	ND (20)	--
Total PeCDD	ND (0.02)	ND (0.02)	ND (0.1)	0.14	0.2	ND (0.02)	ND (20)	--
Total HxCDD	ND (0.02)	ND (0.02)	ND (0.1)	0.259	0.5	0.02	ND	--
Total HpCDD	ND (0.02)	ND (0.02)	ND (0.1)	0.253	0.8	0.02	(20)470	--
Total OCDD	ND (0.02)	ND (0.02)	ND (0.1)	0.081	0.4	0.05	6,700	50B212,000
Total TCDF	ND (0.02)	ND (0.02)	ND (0.1)	0.736	0.03	0.02	ND (20)	--
Total PeCDF	ND (0.02)	0.5	ND (0.1)	0.272	0.2	ND (0.02)	ND (20)	--
Total HxCDF	ND (0.02)	ND (0.02)	ND (0.1)	0.091	0.8	ND (0.02)	ND (20)	--
Total HpCDF	ND (0.02)	ND (0.02)	ND (0.1)	0.03	1.5	0.1	455	--
Total OCDF	ND (0.02)	ND (0.02)	ND (0.1)	0.016	2.1	0.1	2,830	350B58,300
Total CDD/CDF	ND	0.8	ND	1.9	6.5	0.3	10,455	400B270,300

[a]Source: Hutzinger and Fiedler (1991b); unpublished results of tests performed at the University of Bayreuth, Germany, and by Dr. H. Hagenmaier.
[b]Source: Villanueva et al. (1974); range of three samples of commercially available HCBz.
ND = Not detected (value in parenthesis is the detection limit, if reported).
-- = No information given.

Table 8-13. Annual releases in 2000 from complex plants producing chlorine and a variety of chlorinated organics (g I-TEQ/year)

Plant/Location	Chemicals	On-site				Off-site transfers[a]	
		Air	Water	Landfill	Landfarm	Landfill	Incineration
Dow Chemical—Midland MI	Ag chemicals, polymers, others	0.046	0.037	12.6			
Confidence Rating		H/H	H/H	H/H			
Dow Chemical—Plaquemine, LA	Chlorine, EDC, others	0.092	7.71	12.8			
Confidence Rating		H/H	H/H	H/H			
Dow Chemical—Freeport, TX	Chlorine, EDC, VCM, solvents, others	3.08	6.91	89.3			
Confidence Rating		H/H	H/H	H/H			
Company A, Plant A1	Chlorine, EDC, VCM, others	0.068	0.023		1.45	1.5	2.18
Confidence Rating		H/H	H/H		H/H	H/H	H/H
Occidental—Convent, LA	Chlorine, NaOH, EDC	0.022	0.002			0.081	12.1
Confidence Rating		R/H	LR/H			H/H	R/H
Occidental—Ingleside, TX	Cl2 (diaphragm-cell), NaOH, EDC, VCM	1.61	0.018			1.47	
Confidence Rating		RH/H	H/H			H/H	
PPG Industries—Lake Charles, LA	Cl2 (mercury-/diaphragm-cell), hydrogen, NaOH, EDC, and VCM	0.02	8.98			0.303	8.66
Confidence Rating		H/H	H/H			H/H	H/H
Company B, Plant B1	Cl2, solvents, other chlorinated organics	0.037	1.07				0.208
Confidence Rating		R/H	R/H				
Occidental—Niagara Falls	Cl2, NaOH, organic chemicals	3.80×10^{-3}	1.40×10^{-3}			0.028	210
Confidence Rating		H/H	H/H			R/H	R/H
Company B, Plant B2	Cl2, EDC, solvents	8.38×10^{-3}	3.72×10^{-1}				

Table 8-13. Annual Releases in 2000 from complex plants producing chlorine and a variety of chlorinated organics (g I-TEQ/year) (continued)

Plant/Location	Chemicals	On-Site				Off-site Transfers[a]	
		Air	Water	Landfill	Landfarm	Landfill	Incineration
Confidence Rating		R/H	R/H				
Total		4.99	25.12	114.70	1.45	3.38	233.15

[a]The off-site transfers represent the amount going to off-site facilities not the amount released to the environment.
H = High.
R = Reasonable.
L = Low.

Source: Dyke and Amendola (2007).

Table 8-14. CDD/CDF mean concentrations (ng/kg) measured in the 2001 National Sewage Sludge Survey

Congener	Nondetect set to ½ detection limit	Nondetect set to zero
2,3,7,8-TCDD	1.41	1.1
1,2,3,7,8-PeCD	5.76	4.57
1,2,3,4,7,8-HxCDD	11.8	7.49
1,2,3,6,7,8-HxCDD	21.3	15.1
1,2,3,7,8,9-HxCDD	3.6	2.22
1,2,3,4,6,7,8-HpCDD	492	273
OCDD	6,780	2,730
2,3,7,8-TCDF	3.11	2.3
1,2,3,7,8-PeCDF	2.61	1.5
2,3,4,7,8-PeCDF	6.03	2.8
1,2,3,4,7,8-HxCDF	1.37	1
1,2,3,6,7,8-HxCDF	0.27	0
1,2,3,7,8,9-HxCDF	5.21	2.6
2,3,4,6,7,8-HxCDF	5.5	3.36
1,2,3,4,6,7,8-HpCDF	9.13	2.8
1,2,3,4,7,8,9-HpCDF	167	88.2
OCDF	802	279
Average total WHO_{98} TEQ_{DF}	23	14
Average total I-TEQ_{DF}	27	15

Source: EPA (2002d).

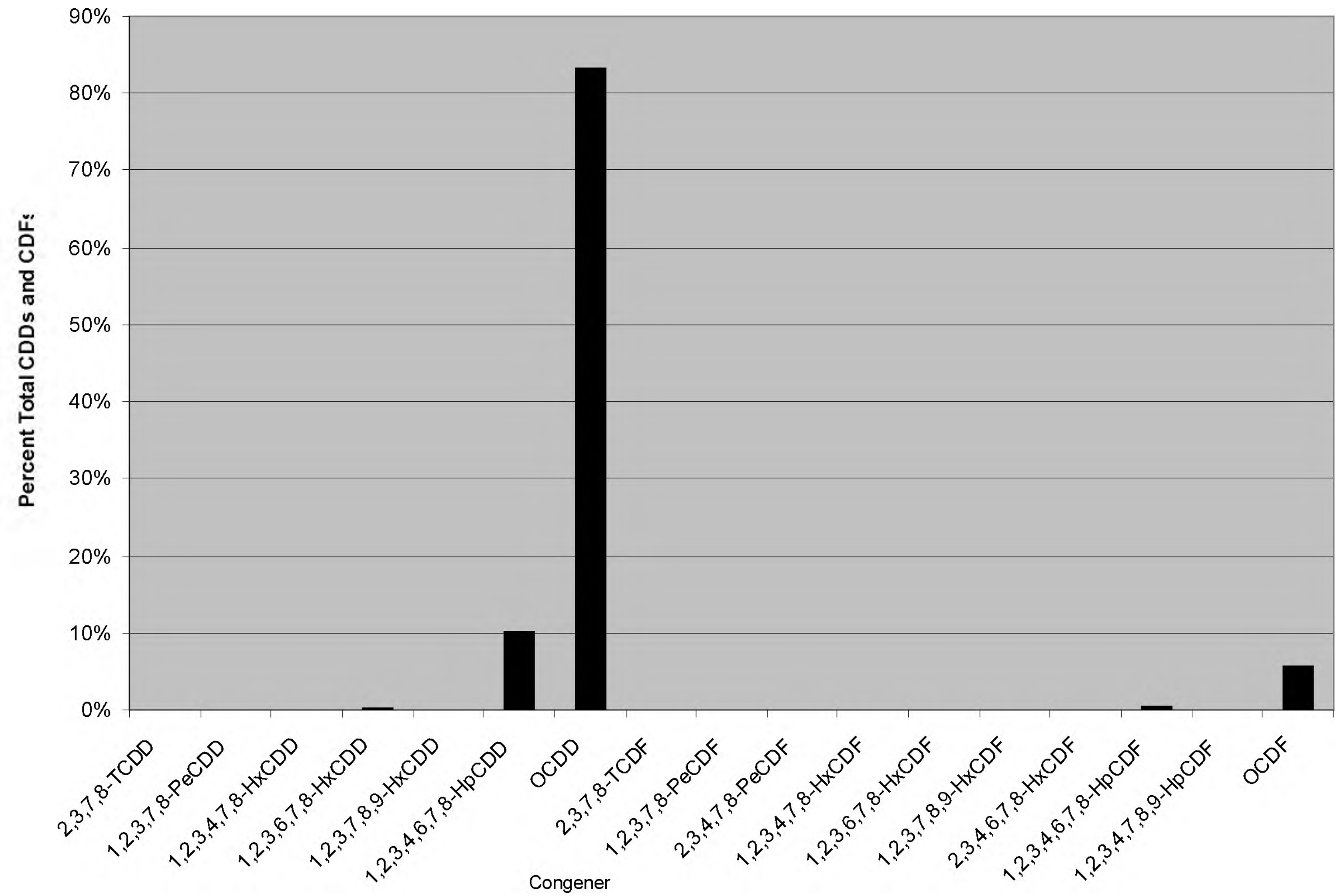

Figure 8-1. Congener profile for technical-grade PCP (developed from data in last column in Table 8-10).

9. NATURAL SOURCES OF CDDS/CDFS

Numerous laboratory and field research studies have demonstrated that biochemical and photolytic formation of CDDs/CDFs from chlorophenol precursors is possible. In addition, under certain conditions, some CDDs/CDFs can be biodegraded to form less-chlorinated (and possibly more toxic) CDDs/CDFs. Both of these mechanisms are discussed in this chapter; however, the extent to which CDDs/CDFs are formed by either mechanism in the environment is unknown at present. The potential for releases of CDDs/CDFs from the application of animal manure to farmland and the mining and use of ball clay are also discussed. Forest fires could be considered a potential natural source, but it was decided that the discussion fit better in Chapter 6 on minimally and uncontrolled combustion sources. Similarly, volcanoes were discussed in Chapter 6 where it indicates that no studies have demonstrated the formation of CDDs/CDFs by volcanoes.

9.1. BIOTRANSFORMATIONS

9.1.1. Biotransformation of Chlorophenols

As discussed in the original report, the biochemical formation of CDDs/CDFs—particularly the higher-chlorinated congeners—from chlorophenol precursors is possible, as indicated in laboratory studies with solutions of trichlorophenols and PCP in the presence of peroxidase enzymes and hydrogen peroxide. However, the extent to which CDDs/CDFs are formed in the environment via this mechanism cannot be estimated at this time.

UNEP (2005) suggests the following emission factors for composted materials: garden and kitchen wastes—15 ng I-TEQ/kg dry matter, and green materials from unimpacted environments—5 ng I-TEQ/kg dry matter. The discussion indicates that some very high levels (approximately 100 ng I-TEQ/kg dry matter) have been observed in compost as a result of contaminated input.

Products from composting operations are typically land spread and have the potential to be a land release. However, insufficient information is available on emission factors and activities to make release estimates for composting or other potential sources involving biotransformation of chlorophenols (Not quantifiable).

Biotransformation of Chlorophenols
Releases to Soil
Not quantifiable.

9.1.2. Biotransformation of Higher CDDs/CDFs

As discussed in the original report, results of several studies that examined the fate of a range of CDD/CDF congeners in pure cultures, sediments, and sludges indicate that under certain conditions, some CDD/CDF congeners will undergo biodegradation to form lower-chlorinated (and possibly more toxic) CDDs/CDFs. However, the extent to which more toxic CDDs/CDFs are formed in the environment via this mechanism cannot be estimated at this time.

Therefore, these releases are not quantifiable.

Biotransformation of Higher CDDs/CDFs
Releases to Soil
Not quantifiable.

9.1.3. Biotransformation of Animal Manure

Because livestock and poultry manure can provide valuable organic material and nutrients for crop and pasture growth, most of the animal manure generated at commercial farms and animal feed lots is applied to farmland as fertilizer. To the extent dioxin-like compounds may contaminate animal manures, the practice of land-spreading animal waste may result in releases of CDDs/CDFs to the open and circulating environment.

Mass balance studies have shown that no new formation of dioxins and furans appears to occur within a cow (Winters et al., 2000; Lorber et al., 2000; McLachlan et al., 1990). These studies have involved measuring the dioxins present in the feeds provided to dairy cows and then measuring the dioxins in the cow milk, feces, and urine in carefully controlled settings. Studies by EPA (Winters et al., 2000; Lorber et al., 2000) involved four cows, sampled three times between July and November of 1997. Preliminary testing on urine showed nondetects as expected, so this matrix was not included in further testing. The tests were designed to represent typical conditions (feed types, dairy cow housing, etc.) in the United States with regard to the production of milk. The feed and feces concentrations ranged from 0.13 to

0.30 ng WHO_{98} TEQ_{DF}/kg dry weight basis, and milk concentrations ranged from 0.53 to 0.96 ng WHO_{98} TEQ_{DF}/kg lipid basis. The feces concentrations in these lactating cows were about one order of magnitude lower than that measured by Stevens and Jones (2003) in the United Kingdom (U.K.) (see Table 9-1). A mass balance was determined by dividing the mass of CDD/CDFs present in feces and milk by the mass in the feed and then multiplying by 100% (a finding of 100% suggests that the dioxins excreted in milk and feces equals that in the feed; a finding greater than 100% suggests formation). These matrices were sampled once the cows were well into lactation, so an assumption of steady state was reasonable. The mass balance of both TEQs and individual congeners ranged from about 50 to 100%, suggesting no internal formation of CDD/CDFs by the cows. The average mass balance over 17 congeners was 73%. McLachlan et al. (1990) conducted a similar experiment with one cow in a background setting and also found mass balances between 50 and 100%, with an average of 75% over all 17 CDD/CDF congeners.

As discussed in the original report, reasonably good data are available on the generation rates of livestock manure. However, limited data are available on CDD/CDF levels in livestock manure. Further, mass balance studies on lactating cows suggest that no new formation of CDD/CDFs are occurring. Thus, while the land application of farm animal manure is a potential land release, it is concluded that insufficient data are available to quantify these releases, and because of the mass balance studies, these may be better characterized as a redistribution rather than a new formation. Accordingly, EPA currently considers this source to be unquantifiable in terms of dioxin emissions.

Biotransformation of Animal Manure
Releases to Soil
Not quantifiable.

9.2. PHOTOCHEMICAL TRANSFORMATIONS

A number of researchers have demonstrated that CDD/CDFs can be formed via various types of photochemical transformations.

9.2.1. Photolysis of PCP

As discussed in the original report, several studies have demonstrated that photolysis of PCP may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis of PCP
Releases to Wood or Air
Not quantifiable.

9.2.2. Photolysis of Higher CDDs/CDFs

As discussed in the original report, a number of studies have demonstrated that photolysis of higher CDD/CDFs may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis of Higher CDDs/CDFs
Releases to Air, Water, or Soil
Not quantifiable.

9.2.3. Photolysis in Water

As discussed in the original report, a number of studies have demonstrated that photolysis in water may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis in Water
Releases to Water
Not quantifiable.

9.2.4. Photolysis on Soil Surfaces

As discussed in the original report, studies have demonstrated that photolysis on soil surfaces may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis on Soil
Releases to Soil
Not quantifiable.

9.2.5. Photolysis on Vegetation

As discussed in the original report, studies have demonstrated that photolysis on vegetation may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis on Vegetation
Releases to Biota
Not quantifiable.

9.2.6. Photolysis in Air

As discussed in the original report, studies have demonstrated that photolysis in air may lead to the formation of CDD/CDFs; however, the information is considered inadequate to estimate releases of CDD/CDFs to the environment.

Photolysis in Air
Releases to Air
Not quantifiable.

9.3. CDDS/CDFS IN BALL CLAY

As discussed in the original report, studies have demonstrated that CDD/CDFs are found naturally in ball clay. Releases from ball clay may occur when it is disturbed during mining and subsequent processing. Accordingly, such releases have both a natural and an anthropogenic aspect to them. Multiplication of the mean WHO_{98} TEQ_{DF} concentration in mined ball clay by the total amount of ball clay mined in 1995 gives an estimate of 1,502 g WHO_{98} TEQ_{DF} (U.S. EPA, 2006). It is unknown how much of these CDD/CDFs contained in mined ball clay are released to the environment during the mining, initial refining, and product handling. Most ball clay is used to produce ceramic products where releases may occur from processes such as drying or high-temperature vitrification. The temperatures found in ceramic kilns vary but can reach levels needed for both volatilization and destruction of CDD/CDFs. No stack measurement data are available from these facilities, so there is insufficient evidence to make even a preliminary estimate of releases.

Ball Clay
Releases to Air
Not quantifiable.

Table 9-1. CDD and CDF concentrations (ng/kg dry weight) in samples of animal manure in the United Kingdom

Congener	Cows[a] (*n* = 6) (mean)	Cows[b] (*n* = 10) (mean)	Sheep[a] (*n* = 1)	Pig[a] (*n* = 1)	Chicken[a] (*n* = 1)
2,3,7,8-TCDD	0.17	0.02	0.11	0.01	0.01
1,2,3,7,8-PeCDD	0.46	0.04	0.41	0.07	0.04
1,2,3,4,7,8-HxCDD	2.4	0.06	0.9	0.26	0.03
1,2,3,6,7,8-HxCDD	4.5	0.15	0.86	0.1	0.09
1,2,3,7,8,9-HxCDD	2.6	0.11	0.56	0.07	0.12
1,2,3,4,6,7,8-HpCDD	120	3.6	9.4	0.8	1.4
OCDD	460	58	53	11	14
Total 2,3,7,8-CDD	590.1	62.3	65.2	12.3	15.7
2,3,7,8-TCDF	0.3	0.05	1.2	0.03	0.03
1,2,3,7,8-PeCDF	0.3	0.04	1.1	0.04	0.09
2,3,4,7,8-PeCDF	0.28	0.06	1.2	0.06	0.12
1,2,3,4,7,8-HxCDF	0.6	0.18	1.4	0.05	0.15
1,2,3,6,7,8-HxCDF	0.51	0.12	1.1	0.06	0.07
1,2,3,7,8,9-HxCDF	1.9	0.05	0.15	0.04	0.05
2,3,4,6,7,8-HxCDF	0.4	0.16	1.4	0.06	0.14
1,2,3,4,6,7,8-HpCDF	7.6	1.8	5.2	0.48	0.37
1,2,3,4,7,8,9-HpCDF	12	0.17	0.56	0.04	0.09
OCDF	35	2.4	5	0.73	0.8
Total 2,3,7,8-CDF	58.9	5.0	18.3	1.6	1.9
Total CDD/CDF	649	67.4	83.5	13.9	17.6
WHO_{98} TEQ	3.6	0.2	2.1	0.2	0.2

Sources: [a]Stevens and Jones (2003); [b]Personal communication, M. Lorber (2008), who provided the raw data for the study summarized in Lorber et al. (2000). The data reflect four cows sampled three times; *n* = 10 instead of 12 because two cows in one sampling date were exposed to feed purposefully contaminated with PCP-treated wood shavings.

10. SOURCES OF DIOXIN-LIKE POLYCHLORINATED BIPHENYLS (PCBS)

This chapter estimates releases of dioxin-like PCB congeners to the environment. PCB releases from media reservoirs (i.e., soil, sediment, and water) are covered in Chapter 11. This chapter covers other PCB sources, primarily conventional point sources. These sources are assumed to have contemporary formation releases. This is uncertain, though, because some portion of these releases may be passed through from inputs to outputs rather than new formation. Both Chapters 10 and 11 contain information on releases associated with PCB products.

10.1. GENERAL FINDINGS OF THE EMISSIONS INVENTORY

The primary changes to this chapter include the addition of several new source categories, addition of background information to a number of the other sources, and minor changes to the release estimates. Additionally, the release summary table (see Table 10-1) has been reformatted to match the new one used for CDD/CDFs.

Relatively few sources have well-characterized releases of dioxin-like PCBs. As shown in Table 10-1, 2 sources had quantitative release estimates, 6 sources had preliminary release estimates and 9 sources were identified as being unquantifiable. Although the information is limited, it suggests that, in terms of TEQs, PCB releases are much lower than CDD/CDF releases.

Two potential source categories that could not be addressed are contaminated PCB sites and wastes with less than 50-ppm PCB (which are not regulated under TSCA). No information was found that would allow evaluation of releases from these sources.

The original report concluded that it is likely that no significant releases of newly formed dioxin-like PCBs are occurring in the United States. This is based on three arguments. First, although the data are limited, the inventory presented here suggests that new releases are low in comparison to the amounts currently present in the environment. As shown in Table 10-1, the total quantitative release estimates for 2000 sum to only about 30 g WHO_{98} TEQ_P/year to air and 20 g WHO_{98} TEQ_P/year to land. As discussed in Chapter 11, the surface soils in the United States are estimated to contain about 95 kg of PCB TEQs. Also, the release estimates may overestimate new releases because some portion may be passed through from inputs to outputs rather than new formation. Second, the new releases appear low compared to past releases associated with PCB production, use, and disposal. As discussed in Section 10.7, an estimated 3,702 kg of WHO_{98} TEQ_P were released directly to the U.S. environment between 1930 and 1977. Third, North American sediment studies have shown decreasing PCB levels since the 1980s (Lebeuf et al., 1995; Cleverly et al., 1996), indicating that releases of newly formed PCBs are not large enough to prevent this decline. Accordingly, the original statement is still believed to likely be true, but it is acknowledged to be uncertain because releases could be estimated for only a few sources.

10.2. RELEASES FROM COMMERCIAL PCB PRODUCTS

10.2.1. Approved PCB Disposal/Destruction Methods

As discussed in the original report, landfilling and incineration can be used as disposal methods for PCBs. It is assumed that the amounts landfilled would not represent an environmental release. The incineration facilities achieve a high combustion efficiency, but some releases are possible. The original report summarizes TRI information on total PCB releases to air, surface water, and land. Insufficient information was available to convert these releases to TEQ estimates.

PCB Incineration
Releases
Not quantifiable.

10.2.2. Releases of In-Service PCBs

As discussed in the original report, insufficient information is available to make quantitative release estimates occurring from in-service PCBs. No changes were made to this conclusion, but some additional background information on accidental fires is provided below. Also, this section was expanded to include nonaccidental releases of in-service PCBs.

A variety of PCB products can remain in use for long time periods, such as paint, caulk, transformers, and capacitors. Releases from these products can occur via vaporization or leaks or during disposal operations. As discussed in the original report (see Section 10.6), approximately 568,000 MT of PCBs were used in the United States between 1930 and 1975. An estimated 50.3% were used in capacitors, and 26.8% were used in transformers. Assuming that these products contained an average of 8 mg WHO_{98} TEQ_P/kg (average concentration for Aroclor 1242, which accounted for over 50% of total sales—see Section 10.6 of original report), then a total of 3,500 kg of WHO_{98} TEQ_P were used in capacitors and transformers. It is unknown how much of this material is still in use today or what amount of releases may be occurring. Note that these products can be considered reservoirs because the releases can occur after their initial use, so they are also discussed in Chapter 11.

A report by the Environment Agency in the United Kingdom assessed the importance of releases of PCBs from various sources (Dyke, 2002). This report concluded that leaks from capacitors and transformers are likely to be the largest source of PCB releases occurring currently, although this is expected to decline as these devices are taken out of service and disposed. Leaks from electrical equipment were estimated to account for 80% of the total PCB releases occurring in the United Kingdom in 1998 (Dyke, 2002).

A number of PCB transformer fires have occurred in the United States, leading to PCB contamination of the interiors of office buildings (Michaud et al., 1994). Soot can be produced in large amounts, consisting of particles that may contain PCB concentrations up to 5,000−8,000 mg/kg of soot (Michaud et al., 1994). The following are several examples of PCB fires in office buildings.

In the case of a transformer fire in the basement of the New York State office building in Binghamton, NY, the circulation of PCB-contaminated soot particles resulted in an average interior surface concentration of 162 mg/m^2 (expressed as the equivalent Aroclor 1254 concentration) (Erickson, 1997). Additionally, the soot samples from the Binghamton PCB fire contained about 20 mg/g and 700 mg/g of total CDDs and total PCDFs, respectively (Erickson, 1997). In 1985, a PCB transformer fire occurred in the basement transformer vault in the main building of the New Mexico State Highway Department Office Building (CDC, 1985). Interior air concentrations of PCBs in the transformer vault were found to average about 48 μg/m^3. Surface wipes on horizontal surfaces had PCB concentrations ranging from 4,700 to 30 million μg/m^2. Other notable U.S. transformer fires include the office building at 1 Marke Plaza in San Francisco in 1983, the Saniford Street office building in Boston in 1981, and the Page Belcher building in Tulsa (Michaud et al., 1994). In these fires, indoor air PCB concentrations ranged from 140 to 1,500 μg/m^3; interior surfaces to the buildings ranged from

20–90 μg/m^2 total PCBs. TCDF concentrations ranged from 4–30 pg/m^3 in the indoor office air and from 200–700 ng/m^2 to interior surfaces.

Releases of In-Service PCBs
Releases
Not quantifiable.

10.3. CHEMICAL MANUFACTURING AND PROCESSING SOURCES

The original report discussed Municipal Wastewater Treatment under Section 10.2. In this update, it has been moved to this section because these facilities are not associated with commercial PCB products and do conduct a type of chemical processing. Minor changes were made to the release estimates as summarized below.

For reference years 1987 and 1995, the concentration of dioxin-like PCBs that may be present in sewage sludge was estimated as 24.3 ng WHO_{98} TEQ_P/kg. This is based on the 1994 survey of 74 plants as reported by Green et al. (1995) and Cramer et al. (1995). For reference year 2000, the concentration of dioxin-like PCBs that may be present in sewage sludge was estimated as 5.22 ng WHO_{98} TEQ_P/kg. This is based on the 2001 survey of 94 plants (U.S. EPA, 2002d). The activity estimates were based on the 1988/1989 National Sewage Sludge Survey and the results of the 1984 to 1996 Clean Water Needs Surveys (U.S. EPA, 1999b). All beneficial uses were assumed to have the potential for release to the environment, resulting in increases in the product release estimates compared to the original report.

As discussed in EPA (2006), there is no clear evidence that other types of chemical manufacturing and processing facilities release dioxin-like PCBs.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Municipal Wastewater Treatment				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.			Yes	
Measured emission factors consistent or have understandable differences.			Yes	
Emission factor tests represent units that are typical of the class.			Yes	
Activity estimates based on source-specific surveys.			Yes	
Conclusion (Q = Quantitative, P = Preliminary).			Q	

Municipal Wastewater Treatment
Soil Releases
Emission Factors • 1987—24 ng WHO_{98} TEQ_P/kg of sludge. • 1995—24 ng WHO_{98} TEQ_P/kg of sludge. • 2000—5.2 ng WHO_{98} TEQ_P/kg of sludge.
Activity Levels • 1987—2.1 MMT of sludge. • 1995—3.2 MMT of sludge. • 2000—3.6 MMT of sludge.
Releases • 1987—51 g WHO_{98} TEQ_P. • 1995—78 g WHO_{98} TEQ_P. • 2000—19 g WHO_{98} TEQ_P.
Product Releases
Emission Factors • 1987—24 ng WHO_{98} TEQ_P/kg of sludge. • 1995—24 ng WHO_{98} TEQ_P/kg of sludge. • 2000—5.2 ng WHO_{98} TEQ_P/kg of sludge.
Activity Levels • 1987—0.07 MMT of sludge. • 1995—0.5 MMT of sludge. • 2000—0.5 MMT of sludge.
Releases • 1987—2 g WHO_{98} TEQ_P. • 1995—12 g WHO_{98} TEQ_P. • 2000—3 g WHO_{98} TEQ_P.

10.4. COMBUSTION SOURCES

10.4.1. Municipal Waste Combustion

The 2006 report concluded that insufficient information was available to develop quantitative release estimates from municipal waste incinerators. A number of additional studies are presented below that allow making preliminary estimates.

Dyke (2002) provides a review of PCB emission factors for municipal waste incinerators. These vary from 0.000027 to 14 ng TEQ_P/kg. Dyke et al. (2003) provide a similar literature survey of 1990's data on incinerator emissions and fly ash concentrations of concurrently measured dioxin-like PCBs and CDD/CDF TEQ. Their literature summary supports the observation that WHO_{98} TEQ_P emission concentrations from MWCs are an order of magnitude and more lower than WHO_{98} TEQ_{DF}. They also provide some PCB emission factors from these references, showing a fairly wide range from as low as 0.0085 to as high as 25.6 μg WHO_{98} TEQ_P/MT. Finally, they provide results of their own testing on two MWCs with different levels of pollution control. For one MWC, three of four tests were nondetect for all 14 PCBs measured and the other test showed some positive concentrations. For the second MWC, two tests had positive measurements for PCB-114, PCB-118, PCB-123, and PCB-180. The range of reported WHO_{98} TEQ_P emission concentrations was between 0 (assuming ND = 0) and 0.016 ng WHO_{98} TEQ_P/Nm^3 (assuming ND = QL).

Sakai et al. (1999) found that the input of coplanar PCBs into the municipal solid waste incineration facilities in Kyoto City (Japan) was 0.13–0.29 mg-TEQ per ton waste, the total output of coplanar PCBs (the sum released from emission gas, fly ash, and bottom ash) was 4.9 mg TEQ per ton waste. The PCB emission factor for gas releases was reported to be 1.2 μg TEQ/ton of waste burned. They reported PCB concentrations in fly ash of 0.053 ng TEQ/g and in bottom ash as 0.000023 ng TEQ/g.

CDD/CDFs and dioxin-like PCBs were measured in the emissions from an MWC in Madrid, Spain, which was equipped with a high level of pollution control (Abad et al., 2006). Over 16 samples, CDD/CDF emissions averaged 0.047 ng I-TEQ/Nm^3, and dioxin-like PCBs added an average of 0.0015 ng I-TEQ/Nm^3, with most of this dioxin-like PCB contribution from PCB-126.

Eight incinerators, including two commercial MWCs, were sampled for CDD/CDFs, PCBs, and HCB in a study conducted in Japan (Kim et al., 2004a). The average concentration over all eight incinerators was 0.281 ng WHO_{98} TEQ_{DF}/Nm^3 for CDD/CDFs and 0.023 ng WHO_{98} TEQ_P/Nm^3 for PCBs, suggesting a factor of difference of 10 on average. The disparity from one of the two MWC incinerators was 0.069 ng WHO_{98} TEQ_{DF}/Nm^3 for CDD/CDF and 0.009 ng WHO_{98} TEQ_P/Nm^3 for PCBs. Emissions were much lower for the other MWC, with reported TEQ concentrations uninformative at 0.000 ng WHO_{98} TEQ_{DFP}/Nm^3.

Francois et al. (2005) provide side-by-side measurements of CDD/CDFs and dioxin-like PCBs, which contradict the observations provided by Dyke et al. (2003). Francois et al. (2005) reports on testing at 15 incinerators including three MWCs in Belgium. The dioxin-like PCBs often dominated the overall TEQ emissions. For example, the average shares of the dioxin-like PCBs to total TEQ were 22, 34, and 97% for the three MWCs. The stack concentrations of dioxin-like PCBs were 0.0008, 0.045, and 0.0034 ng WHO_{98} TEQ_P/Nm^3, compared to corresponding CDD/CDF concentrations of 0.0014, 0.0014, and 0.012 ng WHO_{98} TEQ_{DF}/Nm^3. Based on these concentrations and other plant characteristics, annual dioxin-like PCB emissions were quantified in all of these plants at 0.4, 7.0, and 1.2 mg WHO_{98} TEQ_P/year.

Kim et al. (2005) measured 209 congeners in stack emissions from nine facilities in Japan, including three MWCs. They did not measure CDD/CDFs, but their measured concentrations can be compared with other studies identified above. They detected PCBs at all facilities, with total PCBs ranging from 10−700 ng/Nm^3 and coplanar PCBs in the range of 1−25 ng/Nm^3 (0.008−0.324 ng WHO_{98} TEQ_P/Nm^3). On a class basis, the average from the MWCs was the highest at 0.136 ng WHO_{98} TEQ_P/Nm^3.

The PCB emission factor for municipal waste incinerators was assumed to equal the geometric mean of the range reported by Dyke et al., 2003 (0.0085 to 25.6 μg WHO_{98} TEQ_P/MT) which is 0.5 ng WHO_{98} TEQ_P/kg. This emission factor is considered preliminary due to the inconsistency in the results. The activity data are presented in Chapter 3. PCBs are also likely to be present in the ash, but these would be landfilled and not considered an environmental release. The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Municipal Waste Combustion				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Municipal Waste Combustion
Air Releases
Emission Factors • 1987—0.5 ng WHO_{98} TEQ_P/kg (Preliminary). • 1995—0.5 ng WHO_{98} TEQ_P/kg (Preliminary). • 2000—0.5 ng WHO_{98} TEQ_P/kg (Preliminary).
Activity Levels • 1987—13.7 billion kg. • 1995—29.8 billion kg. • 2000—29.4 billion kg.
Releases • 1987—7 g WHO_{98} TEQ_P (Preliminary). • 1995—15 g WHO_{98} TEQ_P (Preliminary). • 2000—15 g WHO_{98} TEQ_P (Preliminary).

10.4.2. Industrial Wood Combustion

As discussed in EPA (2006), evidence exists that PCBs can be released from industrial wood combustion, but the information is insufficient to make quantitative release estimates. No changes were made to this conclusion.

Industrial Wood Combustion
Releases
Not quantifiable.

10.4.3. Medical Waste Incineration

EPA (2006) concluded that insufficient evidence existed to derive emission factors for PCB releases from medical waste combustion. As discussed below, additional studies were found that allowed making preliminary release estimates.

Dyke et al. (2003) surveyed the literature for studies providing measurements of dioxin-like PCBs along with CDD/CDFs from power stations and waste incineration processes. They identified a study published in 1996 (Ehrlich et al., 1996) in which the PCB emission concentration from a medical waste incineration was 0.035 ng WHO_{98} TEQ_P/Nm^3, while it was 0.97 ng WHO_{98} TEQ_{DF}/Nm^3 for CDD/CDFs. They also conducted their own measurements on a medical waste incinerator in the United Kingdom. They quantified concentrations of PCB-118, PCB-123, PCB-170, and PCB-180—but not the other 14 congeners. Assuming ND = 0, one of two runs had a concentration of 0.00007 ng WHO_{98} TEQ_P/Nm^3, while the other had a concentration of 0.022 WHO_{98} TEQ_P/Nm^3 at ND = 0. In contrast, the same two runs had CDD/CDF concentrations at ND = 0 at 0.07 and 0.05 ng WHO_{98} TEQ_{DF}/Nm^3.

The data reported by Dyke et al. (2003) suggest that PCB TEQ emissions are 1 to 25% of the dioxin emissions. The Ehrlich et al. (1996) data suggest that the PCB TEQ emissions are 4% of the dioxin emissions. The Ehrlich et al. (1996) value was selected as a central estimate and multiplied by the average CDD/CDF emission factor for each reference year (total CDD/CDF emissions divided by the total activity as reported in Chapter 3). This procedure gave the emission factors shown below. These emission factors are considered preliminary because the studies provided insufficient information to directly derive them. The activity data are presented in Chapter 3. PCBs are also likely to be present in the ash, but these would be landfilled and not considered an environmental release. The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Medical Waste Incineration				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.	Yes			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Medical Waste Incineration
Air Releases
Emission Factors • 1987—68 ng WHO_{98} TEQ_P/kg (Preliminary). • 1995—24 ng WHO_{98} TEQ_P/kg (Preliminary). • 2000—24 ng WHO_{98} TEQ_P/kg (Preliminary).
Activity Levels • 1987—1.43 billion kg. • 1995—0.77 billion kg. • 2000—0.6 billion kg.
Releases • 1987—97 g WHO_{98} TEQ_P (Preliminary). • 1995—18 g WHO_{98} TEQ_P (Preliminary). • 2000—14 g WHO_{98} TEQ_P (Preliminary).

10.4.4. Tire Combustion

As discussed in EPA (2006), evidence exists that PCBs can be released from tire combustion, but the information is insufficient to make quantitative release estimates. No changes were made to this conclusion.

Tire Combustion
Releases
Not quantifiable.

10.4.5. Cigarette Smoking

As discussed in the original report, PCB releases can occur during cigarette smoking. No changes were made to these estimates as summarized below.

A preliminary estimate of potential emissions of dioxin-like PCBs can be made using the following assumptions: (a) the average WHO_{98} TEQ_P content of seven brands of U.S. cigarettes reported by Matsueda et al. (1994), 0.64 pg/pack (0.032 pg/cigarette), is representative of cigarettes smoked in the United States; (b) dioxin-like PCBs are neither formed nor destroyed, and the congener profile reported by Matsueda et al. (1994) is not altered during combustion of cigarettes; and (c) all dioxin-like PCBs contributing to the TEQ are released from the tobacco during smoking. This emission factor is considered preliminary because of the multiple assumptions required in its derivation. Cigarette consumption is discussed in Section 5.5.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Cigarette Smoking				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.				
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Cigarette Smoking
Air Releases
Emission Factors • 1987—0.03 pg WHO_{98} TEQ_P/cigarette (Preliminary). • 1995—0.03 pg WHO_{98} TEQ_P/cigarette (Preliminary). • 2000—0.03 pg WHO_{98} TEQ_P/cigarette (Preliminary).
Activity Levels • 1987—575 billion cigarettes. • 1995—487 billion cigarettes. • 2000—440 billion cigarettes.
Releases • 1987—<0.1 g WHO_{98} TEQ_P (Preliminary). • 1995—<0.1 g WHO_{98} TEQ_P (Preliminary). • 2000—<0.1 g WHO_{98} TEQ_P (Preliminary).

10.4.6. Sewage Sludge Incineration

As discussed in the original report, PCB releases can occur from sewage sludge incineration. No changes were made to these estimates as summarized below. Additional information was found regarding a stack test for a sewage sludge incinerator in the United Kingdom (Dyke et al., 2003). This was not used in the emission factor derivation because all dioxin-like PCB congeners were below the detection limits of about 0.12 ng/Nm^3 for each congener.

The emission factor was based on measurements conducted at a multiple-hearth incinerator in Ohio equipped with a venturi scrubber and a three-tray impingement conditioning tower (U.S. EPA, 2000b). This emission factor was considered preliminary because it is based on testing at only one facility. Sewage sludge activity data are presented in Chapter 8.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Sewage Sludge Incineration				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.				
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Sewage Sludge Incineration
Air Releases
Emission Factors • 1987—0.51 ng WHO_{98} TEQ_P/kg of sludge (Preliminary). • 1995—0.51 ng WHO_{98} TEQ_P/kg of sludge (Preliminary). • 2000—0.51 ng WHO_{98} TEQ_P/kg of sludge (Preliminary).
Activity Levels • 1987—0.865 MMT. • 1995—2.11 MMT. • 2000—1.42 MMT.
Releases • 1987—0.4 g WHO_{98} TEQ_P (Preliminary). • 1995—1 g WHO_{98} TEQ_P (Preliminary). • 2000—0.7 g WHO_{98} TEQ_P (Preliminary).

10.4.7. Backyard Barrel Burning

The original report concluded that insufficient information was available to make quantitative PCB release estimates for backyard barrel burning. New information is provided below, which allowed making both air and land release estimates for this source category.

Gonczi et al. (2005) tested emissions from burning domestic wastes in barrels (19 tests) and open fires (2 tests). Gas collected above these fires allowed for estimation of emission factors. The material burned consisted of various mixtures of garden wastes, straw, paper, several forms of plastic, tires, waste motor oil, RDF, and computer scrap. A barrel burn with a mix of garden waste and polyvinyl chloride (PVC) waste had the highest emission factor of 190 ng PCB TEQ/kg burned. The other tests ranged from 0.3 to 3.2 ng WHO_{98} TEQ_P/kg burned. The dioxin-like PCBs generally made up much less than 10% of the total TEQ emissions.

As reported in EPA (2006), Lemieux (1997) also measured PCB emissions from tests simulating backyard barrel burning. The average emission factor across two tests was 5.26 ng WHO_{98} TEQ_P/kg waste burned. This emission factor was selected as the most representative of typical domestic waste.

Lemieux (1997) also collected ash samples from open barrel burning and analyzed for PCBs. Ash samples from the experiments were combined, resulting in two composite samples—one for recyclers and one for nonrecyclers (see Table 10-2). The overall average was 0.8 ng WHO_{98} TEQ_P/kg of ash.

The activity levels for backyard barrel burning (total waste burned and ash generated) were presented in Section 6.5.2.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Backyard Barrel Burning

	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes		Yes	
Measured emission factors consistent or have understandable differences.	Yes		Yes	
Emission factor tests represent units that are typical of the class.	Yes		Yes	
Activity estimates based on source-specific surveys.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	Q		Q	

Backyard Barrel Burning
Air Releases
Emission Factors • 1987—5.3 ng WHO_{98} TEQ_P/kg of waste burned. • 1995—5.3 ng WHO_{98} TEQ_P/kg of waste burned. • 2000—5.3 ng WHO_{98} TEQ_P/kg of waste burned.
Activity Levels • 1987—7.87 MMT. • 1995—8.18 MMT. • 2000—6.49 MMT.
Releases • 1987—41 g WHO_{98} TEQ_P. • 1995—43 g WHO_{98} TEQ_P. • 2000—34 g WHO_{98} TEQ_P.
Solid Residue Releases
Emission Factors • 1987—0.8 ng WHO_{98} TEQ_P/kg of ash. • 1995—0.8 ng WHO_{98} TEQ_P/kg of ash. • 2000—0.8 ng WHO_{98} TEQ_P/kg of ash burned.
Activity Levels • 1987—1.2 MMT. • 1995—1.2 MMT. • 2000—0.97 MMT.
Releases • 1987—1 g WHO_{98} TEQ_P. • 1995—1 g WHO_{98} TEQ_P. • 2000—0.8 g WHO_{98} TEQ_P.

10.4.8. Petroleum Refining Catalyst Regeneration

As discussed in EPA (2006), evidence exists that PCBs can be released from petroleum refining catalyst regeneration, but the information is insufficient to make quantitative release estimates. No changes were made to this conclusion.

Petroleum Refining Catalyst Regeneration
Air Releases
Not quantifiable.

10.4.9. Hazardous Waste Incineration

This is a completely new section on hazardous waste incineration.

Two studies were identified from outside of the United States that measured emissions of dioxin-like PCBs along with dioxins and furans from hazardous waste incinerators. One of the studies was consistent with studies on municipal solid waste incinerators, which showed CDD/CDF TEQ emissions to be an order of magnitude and more higher than PCB emissions. Kim et al. (2005) measured 209 congeners in stack emissions from nine facilities, which included two industrial waste incinerators and a “specific industrial waste incinerator.” The emission concentrations of the dioxin-like PCBs in the industrial waste incinerators were 0.136 for the “specific” incinerator and 0.025 ng WHO_{98} TEQ_P/Nm^3 for the average of the two industrial waste incinerators. These were characterized as being equal to 2.9 and 1.3% of the emission concentrations of WHO_{98} TEQ_{DF}. On the other hand, Francois et al. (2005) measured dioxins, furans, and coplanar PCBs from 15 facilities including one HWI. The concentration of the PCBs was 0.0051 ng WHO_{98} TEQ_P/Nm^3, which was almost three times higher than the measurement of CDD/CDFs, at 0.0019 ng WHO_{98} TEQ_P/Nm^3. The annual emission of dioxin-like PCBs from this facility was estimated at 1.5 mg WHO_{98} TEQ_P/year. Given the inconsistent results from these two studies, it is unclear how to make emission estimates on even a preliminary basis.

Therefore, the available data were judged inadequate to support development of a quantitative estimate of a dioxin-like PCB emission factor for this source category.

Hazardous Waste Incineration
Releases
Not quantifiable.

10.4.10. Power Plants

This is a completely new section.

Emissions from power plants were estimated to account for 2% of the total PCB releases occurring in the United Kingdom in 1998 (Dyke, 2002).

Brodsky et al. (2003) reported on measurements from six combustion sources in Russia, including two power plants. Numerous individual congener concentrations in the stack gas emissions were provided including some dioxin-like PCBs, although no TEQ estimates were provided and no congener-specific emission factors were provided. Concentrations were provided for PCB-105, PCB-118, PCB-123, PCB-156, PCB-157, PCB-170, and PCB-180. The TEQ concentration in the power plant for these congeners was 0.02 ng WHO_{98} TEQ_P/Nm^3.

Francois et al. (2005) reported on testing at 15 incinerators including one coal-fired power plant. They measured emissions of CDD/CDF and PCB as 0.0003 ng WHO_{98} TEQ_{DF}/Nm^3 and 0.0009 ng WHO_{98} TEQ_P/Nm^3, respectively. Extrapolating to annual emissions, they estimated an emission of 1.17 mg WHO_{98} TEQ_P/year. Dyke et al. (2003) reported on emission measurements from a coal-fired power station in the United Kingdom. They found nondetects for all dioxin-like PCBs tested, except a positive for PCB-180 in one of two tests.

The available data were judged inadequate to support development of a quantitative estimate of a dioxin-like PCB emission factor for this source category.

Power Plants
Releases
Not quantifiable.

10.4.11. Forest Fires

This is a completely new section.

Collet and Fianni (2006) conducted five forest fire test burns in a chamber of about 80 m^3. The samples were collected from forests in two regions of southern France and the tests were conducted by the French Agency for Environment and Energy Management. Blank samples were also taken to ensure that the chamber did not introduce contaminants to the burns. Emission concentrations were determined for the 17 CDD/CDFs and 12 dioxin-like PCBs. Generally, PCBs explained about 6% of the total TEQ emissions, except for one forest fire burn, where emissions overall were close to blanks and PCBs contributed 26% in this case. The emission factors for CDD/CDFs ranged from 1.0 ng I-TEQ_{DF}/kg burned (the low for the test close to the blank) to 26 ng I-TEQ_{DF}/kg. The TEF scheme used to characterize PCB emissions was not clear but assumed here to be WHO_{98}. This implies that the PCB emission factor ranged from 0.06 to 1.6 WHO_{98} TEQ_P.

For the purposes of deriving a preliminary estimate, it is assumed that the PCB TEQ emission factor is 6% of the one for CDD/CDFs (based on the results from Collet and Fianni [2006]). As discussed in Chapter 6, the forest fire emission factor is 3 ng WHO_{98} TEQ_{DF}/kg. This is adjusted to 0.2 ng WHO_{98} TEQ_{P}/kg for PCBs. This emission factor is considered preliminary because it is uncertain how well the limited testing represents all fire/wood types. The activity levels for forest fires are presented in Chapter 6. PCBs are also likely to be present in the ash, but insufficient information was available to make quantifiable estimates.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Forest Fires				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	Yes			
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Forest Fires
Air Releases
Emission Factors • 1987—0.2 ng WHO_{98} TEQ_P/kg (Preliminary). • 1995—0.2 ng WHO_{98} TEQ_P/kg (Preliminary). • 2000—0.2 ng WHO_{98} TEQ_P/kg (Preliminary).
Activity Levels • 1987—61 MMT. • 1995—55 MMT. • 2000—243.8 MMT.
Releases • 1987—12 g WHO_{98} TEQ_P (Preliminary). • 1995—11 g WHO_{98} TEQ_P (Preliminary). • 2000—49 g WHO_{98} TEQ_P (Preliminary).
Solid Residue Releases
Not quantifiable.

10.5. METAL REFINING SOURCES

This is a completely new section.

Kim et al. (2004) measured all 209 PCB congeners in stack emissions from nine facilities, including a sintering furnace in a ferrous metal foundry and two smelting furnaces in nonferrous metal foundries in Japan. All nine facilities emitted PCBs, with total PCBs ranging from 10−700 ng/Nm^3 and coplanar PCBs in the range of 1−25 ng/Nm^3 (0.008−0.324 ng WHO_{98} TEQ_P/Nm^3). The three metal facilities had these results: aluminum smelting furnace—0.020 ng WHO_{98} TEQ_P/Nm^3; copper smelting furnace—0.026 ng WHO_{98} TEQ_P/Nm^3; and sintering furnace—0.018 ng WHO_{98} TEQ_P/Nm^3. In terms of a relationship to CDD/CDFs, Kim et al. (2004) developed a ratio of the TEQ concentration of dioxin-like PCBs to that of CDD/CDFs and found the narrow range of 0.032 to 0.050, suggesting that the TEQ concentration of dioxin-like PCBs was over an order of magnitude lower than that of CDD/CDFs.

Stack gas emissions of dioxin-like PCBs were measured along with CDD/CDFs from three iron ore sintering plants in the United Kingdom between 2002 and 2003 (Aries et al., 2006). The dioxin-like PCBs found at the highest concentrations were PCB-118 at 6−9 ng/Nm^3, followed by 105 at 2−4 ng/Nm^3, and 77 at 2−3 ng/Nm^3, with others detected at below 2 ng/Nm^3. On a TEQ basis, including CDD/CDFs and dioxin-like PCBs (the authors calculated CDD/CDF using I-TEFs while dioxin-like PCB TEQ was calculated using WHO_{98} TEFs), the PCBs contributed less than 10% of the total TEQ concentration, which averaged between 0.6 and 1.6 ng total TEQ/Nm^3. The mass emissions of total TEQ from the three plants, calculated based on emission concentrations in conjunction with mass loadings, totaled 8.7, 9.2, and 10.9 g TEQ/year over the three plants.

Kim et al. (2004a) reported on the testing of eight incinerators including two sintering furnaces and four smelting furnaces for CDD/CDFs, PCBs, and HCB. The average over all eight incinerators, on a WHO_{98} TEQ basis, was 0.281 ng/Nm^3 for CDD/CDFs and 0.023 ng/Nm^3 for PCBs, suggesting a factor of 10 difference on average. The aluminum nonferrous metal smelter showed a PCB TEQ concentration at 0.016 ng WHO_{98} TEQ_P/Nm^3, which was only one-half that of CDD/CDF TEQ, not the order of magnitude suggested by averaging all eight facilities. The copper smelter had the same TEQ concentration for both PCBs and CDD/CDFs: 0.002 ng WHO_{98} TEQ_P/Nm^3. The most informative tests, perhaps, were the two iron ferrous metal smelters, where CDD/CDF overwhelmed PCB emissions. The CDD/CDF emission concentrations were 1.492 and 0.926 ng WHO_{98} TEQ_{DF}/Nm^3, while the PCB emission concentrations were 0.112 and 0.067 ng WHO_{98} TEQ_P/Nm^3, respectively.

Brodsky et al. (2003) reported on measurements from six combustion sources in Russia, including a nonferrous metallurgy plant, a cement plant, an aluminum plant in the calcination furnace, and an aluminum plant in the entry into the electrostatic filter. Numerous individual congener concentrations in the stack gas emissions were provided including some dioxin-like PCBs, although no TEQ estimates were provided and no congener-specific emission factors were provided. Concentrations were provided for PCB-105, PCB-118, PCB-123, PCB-156, PCB-157, PCB-170, and PCB-180. The TEQ concentration in these four facilities ranged from 0.001 to 0.006 ng WHO_{98} TEQ_P/Nm^3. Brodsky et al. (2003) provided a total concentration (sum of all congeners) and an emission factor of total PCBs in μg/MT.

Fisher et al. (2004) reported on tests for an experimental sinter box apparatus, which is essentially a small pilot plant. A raw mix of typical iron ore feed—including iron ore fines, fluxes, fuel in the form of coke, and some recycled materials—was combined with five different amounts of potassium chloride to test the effect of chloride on CDD/CDF and dioxin-like PCB emissions. A correlation was found for both CDD/CDF and dioxin-like PCB emissions with chloride content. At a chloride concentration in the entire feed of 250 mg/kg and less, which encompassed a baseline run and a run at 250 mg/kg chloride, CDD/CDF emissions were fairly steady, suggesting chloride did not affect emissions at concentrations in this range, but at higher concentrations with up to about 800 mg/kg chloride added, the effect was second order. For PCBs, the effect was more linear—a linear rise in PCB emissions was noted with increasing chloride content. PCDF concentrations dominated CDD/CDF, and on a TEQ basis, CDD/CDF dominated over PCBs. Specifically, the ratio of PCB to CDD/CDF TEQ concentrations was in the range of 0.07 for the five tests. On a TEQ basis, PCB-126 contributed 90−95% of total PCB TEQ, but PCB-105 and PCB-118 contributed the most on a straight concentration basis. The authors concluded that at typical chloride concentrations of 50−100 mg/kg in the industry, the total CDD/CDF/PCB concentrations are expected to be below 1.5 ng TEQ/Nm^3.

Francois et al. (2004) measured emissions at 15 facilities, including two metal smelters and an iron ore sintering plant. For most facilities, their sampling indicated that the TEQ emissions of dioxin-like PCBs nearly matched that of dioxins. With the iron ore sintering plant, however, the dioxin-like PCBs were an order of magnitude less than dioxins: 0.058 ng WHO_{98} TEQ_P/Nm^3 versus 0.65 ng WHO_{98} TEQ_{DF}/Nm^3. For the aluminum and copper smelters, PCB emissions were a factor of 2 (at 0.046 ng WHO_{98} TEQ_P/Nm^3) and a factor of 4 (at 0.017 ng WHO_{98} TEQ_P/Nm^3) less than dioxin TEQ, respectively. They calculated total annual TEQ emissions for these plants and estimated dioxin-like PCB emissions to be 2.3 and 18.8 mg WHO_{98} TEQ_P/year for the aluminum and copper smelters, respectively, and to be much higher at 474 mg WHO_{98} TEQ_P/year for the iron ore sintering plant.

As described above, several studies outside of the United States have measured dioxin-like PCBs along with CDD/CDFs from a variety of metal processing facilities including ferrous and nonferrous smelters, iron ore sintering facilities, and other combustion units within the metal refining industry. These studies did not report emission factors but the concentration data consistently suggest that emissions from iron ore sintering plants are about an order of magnitude or more lower than CDD/CDFs, on a TEQ basis. Accordingly, for the purposes of a preliminary estimate, the PCB emission factor is assumed to be 10% of the CDD/CDF emission factor. The activity levels (from Chapter 7) and release estimates are shown below. The studies also indicate that PCB emissions are occurring from copper and aluminum smelting operations, but the results are not consistent and not easily converted to TEQ emission factors. Thus, quantitative estimates could not be made for these facilities.

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Iron Ore Sinter Production				
	Air	Water	Solids	Products
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	No			
Measured emission factors consistent or have understandable differences.				
Emission factor tests represent units that are typical of the class.				
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Iron Ore Sinter Production
Air Releases
Emission Factors ***Wet Scrubber*** • 1987—0.06 ng WHO_{98} TEQ_P/kg of sinter (Preliminary). • 1995—0.06 ng WHO_{98} TEQ_P/kg of sinter (Preliminary). • 2000—0.06 ng WHO_{98} TEQ_P/kg of sinter (Preliminary). ***Fabric Filter*** • 1987—0.5 ng WHO_{98} TEQ_P/kg of sinter (Preliminary). • 1995—0.5 ng WHO_{98} TEQ_P/kg of sinter (Preliminary). • 2000—0.5 ng WHO_{98} TEQ_P/kg of sinter (Preliminary).
Activity Levels[a] • 1987—14.5 MMT. • 1995—12.4 MMT. • 2000—10.6 MMT.
Releases • 1987—4 g WHO_{98} TEQ_P (Preliminary). • 1995—3 g WHO_{98} TEQ_P (Preliminary). • 2000—3 g WHO_{98} TEQ_P (Preliminary).

[a]Fifty-nine percent of sinter production was at facilities with wet scrubbers, and 41% was at facilities with fabric filters.

Copper and Aluminum Smelting
Air Releases
Not quantifiable.

10.6. NATURAL SOURCES (ORIGINALLY SECTION 10.5)

As discussed in EPA (2006), there is no clear evidence that releases of dioxin-like PCBs occur from natural sources. No changes were made to this conclusion.

10.6.1. Biotransformation of Other PCBs

As discussed in the original report, studies have shown that under anaerobic conditions, biologically mediated reductive dechlorination to lower-chlorinated congeners, followed by slow anaerobic and/or aerobic biodegradation, is a major pathway for destruction of PCBs in the environment. This research indicates that biodegradation should result in a net decrease rather than a net increase in the environmental load of dioxin-like PCBs.

10.6.2. Photochemical Transformation of Other PCBs

Photolysis and photo-oxidation may be major pathways for destruction of PCBs in the environment. Research reported to date and summarized in the original report indicates that ortho-substituted chlorines are more susceptible to photolysis than are meta- and para-substituted congeners; thus, photolytic formation of more toxic dioxin-like PCBs may occur. Oxidation by hydroxyl radicals, however, apparently occurs preferentially at the meta and para positions, resulting in a net decrease rather than a net increase in the environmental load of dioxin-like PCBs.

10.7. PAST USE OF COMMERCIAL PCBS (ORIGINALLY SECTION 10.6)

This section provides background information about the amount of PCBs used in the past and does not discuss release estimates for the reference years. No changes were made to this section. As discussed in the original report, an estimated 568,000 MT of PCBs were sold in the United States between 1930 and 1975. The environmental releases associated with production, use, and disposal during this time period were estimated as 3,702 kg WHO_{98} TEQ_P.

Table 10-1. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_P/year)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Releases from commercial PCB products												
PCB incineration			x						x			
Releases from in-service PCBs			x			x			x			
Chemical manufacturing and processing sources												
Municipal wastewater treatment												
1987				51						2		
1995				78						12		
2000				19						3		
Combustion sources												
Municipal waste combustors												
1987		7										
1995		15										
2000		15										
Industrial wood combustion			x									
Medical waste incineration												
1987		97										
1995		18										
2000		14										
Tire combustion			x									

Table 10 1. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_P/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Cigarette smoking												
1987		<0.1										
1995		<0.1										
2000		<0.1										
Sewage sludge incineration												
1987		0.4										
1995		1										
2000		0.7										
Backyard barrel burning												
1987	41			1								
1995	43			1								
2000	34			0.8								
Petroleum-refining catalyst regeneration			x									
Hazardous waste incineration			x									
Power plants			x									
Forest fires						x						
1987		12										
1995		11										
2000		49										

Table 10 1. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO_{98} TEQ_P/year) (continued)

Source	Air releases			Land releases			Water releases			Product releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Metal refining												
Iron ore sintering												
1987		4										
1995		3										
2000		3										
Copper smelting			x									
Aluminum smelting			x									
Total												
1987	41	120		52						2		
1995	43	48		79						12		
2000	34	82		20						3		

x = Releases are possible during this year, but the data are insufficient to develop estimates.
Q. Inv. = Quantitative Inventory.
Prelim. = Preliminary.
NQ = Not quantified.

Table 10-2. PCB analysis for composite ash samples from barrel burning

Congener	IUPAC number	Emission factors (μg/kg)		
		Recycler	Nonrecycler	Average
3,3',4,4'-TCB	77	1.2	1	1.1
3,4,4',5-TCB	81			
2,3,3',4,4'-PeCB	105	3.4	3.5	3.5
2,3,4,4',5-PeCB	114			
2,3',4,4',5-PeCB	118			
2',3,4,4',5-PeCB	123			
3,3',4,4',5-PeCB	126			
2,3,3',4,4',5-HxCB	156	0.7	<0.5	0.5
2,3,3',4,4',5'-HxCB	157			
2,3',4,4',5,5'-HxCB	167			
3,3',4,4',5,5'-HxCB	169			
2,3,3',4,4',5,5'-HpCB	189	0.6	<0.5	0.4
Total WHO_{98} TEQ_P		0.0009	0.0006	0.0008

Averages and TEQs calculated assuming half the values for entries shown as less than.

IUPAC = International Union of Pure and Applied Chemistry.
Source: Lemieux (1997).

11. RESERVOIR SOURCES OF CDD/CDFS AND DIOXIN-LIKE PCBS

This introduction has been expanded to more clearly define reservoirs. Chapters 2 through 10 of this document discuss sources with the potential for initial releases of dioxin-like compounds to the environment in the United States. This chapter addresses releases from reservoirs that are defined as materials or places that contain previously released CDD/CDFs or dioxin-like PCBs and have the potential for redistributing these compounds into the environment. Potential reservoirs include soils, sediments, biota, water, and some products. Products that contain CDD/CDFs can be considered reservoirs when they have the potential for releases after their initial use. The atmosphere could be considered a reservoir but is excluded here because it is the primary medium for transporting and distributing CDDs and CDFs over large geographical areas. Thus, it is considered a temporary holding place rather than a long-term reservoir. Although water is also an important transport medium, the residence times can be long, and, therefore, it is appropriately considered a reservoir.

The definition of reservoirs as used in this document also excludes CDD/CDFs contained in natural ball clay deposits. The CDD/CDFs contained in ball clay were formed by geochemical processes that are thought to have occurred millions of years ago. Any release from ball clay would be an initial release to the contemporary environment, and, therefore, ball clay is not considered to be a reservoir. Potential ball clay releases are covered in Chapter 9 on Natural Sources.

Soils in some locations could have elevated CDD/CDF levels due to past activities such as pesticide use, spills, illegal disposal, or fires. These areas would be considered part of the soil reservoir and would have the potential for greater release rates than normal soils with background CDD/CDF levels. The soil-release estimates presented in this document do not include releases from these “hot spots” due to lack of appropriate information. However, they could be important events on a local scale and should be considered where feasible.

Dioxin-like compounds are sequestered by a reservoir only until physical processes cause these contaminants to become released into the open environment over a defined time and space. When this occurs, reservoirs become sources of dioxin-like compounds in the circulating environment. Figure 11-1 presents a conceptual diagram of flux and exchange of dioxin-like compounds to multiple environmental compartments such as soils, water, air, sediments, and biota. This dynamic system consists of fluxes in and out of the atmosphere as well as other exchanges between reservoirs and the atmosphere (recall that the atmosphere is not defined here as an environmental reservoir, rather as a transport medium for dioxin-like compounds). Movement of dioxin-like compounds between media can be induced by the physical processes of volatilization, wet and dry atmospheric particle and vapor deposition, adsorption, erosion and runoff, resuspension of soils into air, and resuspension of sediments into water.

This chapter describes the major reservoir sources of CDD/CDFs and PCBs, including, to the extent feasible, estimates of the potential mass of CDD/CDFs and PCBs in each reservoir, the chemical/physical mechanisms responsible for releases of these compounds, and estimates of potential annual releases from each reservoir.

11.1. SOIL RESERVOIRS (ORIGINALLY SECTION 11.2.1)

This section provides revised estimates of the amounts of CDD/CDFs in soil reservoirs.

Harrad and Jones (1992) and Duarte-Davidson et al. (1997) estimated the CDD/CDF content of soils in the United Kingdom by multiplying the soil surface area by the contamination depth, soil density, and CDD/CDF concentration in the soil. A similar approach was used here to estimate the amount CDD/CDFs in surface soils of the United States. The following inputs were used in these calculations:

- Surface soils were divided into rural and urban areas to reflect differences in the CDD/CDF levels. Urban areas were assumed to have an average concentration of 10 pg WHO TEQ_{DF}/g, and rural soils, 2 pg WHO TEQ_{DF}/g (U.S. EPA, 2007b).
- The urban land area in the United States is 1.82 million km^2 based on Census Bureau statistics for metropolitan areas (USDA, 2002). The portion of urban areas covered by impervious surfaces (rather than soil) varies widely. For the purposes of a preliminary estimate, it was assumed that an average of 50% of the metropolitan land area had soil coverage. The land area of nonmetropolitan areas in the United States is 7.28 million km^2 (USDA, 2002).
- The soil density was assumed to be 2.6 g/cm^3 (Brady, 1984).
- The contamination depth was assumed to be 10 cm (U.S. EPA, 2007b).

Based on these assumptions, the amount of CDD/CDFs in U.S. surface soils was estimated as 2,370 kg WHO TEQ_{DF} in urban soils and 3,790 kg WHO TEQ_{DF} in rural soils, for a total of

6,150 kg WHO TEQ_{DF}. EPA (2007b) found that average PCB TEQs were about 4% of average total D/F/P TEQs in rural soils. Assuming this percentage applies to urban areas as well, this would imply that the soil reservoir contains about 95 kg WHO TEQ_{P}. These calculations are not definitive and only indicate approximate amounts of dioxins that may be contained in U.S. surface soils.

Soils in some locations could have elevated CDD/CDF levels (or "hot spots") due to uncontrolled activities such as spills, illegal disposal, or fires. Elevated soil levels could also occur in areas where 2,4-D and 2,4,5-T were used and areas with land-applied sludges/ash. These areas would be considered part of the soil reservoir and would have the potential for greater release rates than normal soils with background CDD/CDF levels. The amounts in landfills could also be considered part of the soil reservoir, although the potential for release is much less. No estimates could be made for the additional CDD/CDF soil burdens due to the uncontrolled activities, but estimates were made for the other activities as discussed below.

Estimates can be made for the total mass of CDD/CDF TEQs that have been applied to soil from past use of the pesticides 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). As discussed in Chapter 11 of the original report, the total amounts of CDD/CDF released to the environment are as follows:

- From 2,4-D use during the period of 1975 to 1995, the total release was estimated as 0.55 kg WHO_{98} TEQ_{DF} (0.35 kg I-TEQ_{DF}).
- From 2,4,5-T use over the period of 1950 to 1979, the total release was estimated as 36 kg of 2,3,7,8-TCDD.

The amounts of CDD/CDFs in landfills can also be considered a soil reservoir with the potential for releases in the future. The earlier chapters provided estimates of the amounts of CDD/CDFs landfilled for many sources. As shown in Table 11-1, the total amounts landfilled were estimated as 3,750 g TEQ in 1987, 1,050 g TEQ in 1995, and 1,310 g TEQ in 2000. If it is assumed that most landfills operate for 30 years and the average annual input equals the average over the reference years (2,040 g TEQ), then the cumulative sum would be 61,000 g TEQ. This should be regarded as a preliminary estimate because it is based on numerous assumptions and limited data.

A variety of waste types containing CDD/CDFs are land applied such as sewage sludge, wood pulp sludge, residential wood burning ash, and beneficial uses of cement kiln clinker. These sources also contribute to the soil reservoir. As shown in Table 1-9, these sum to 2,400 g TEQ in 1987, 2,500 g TEQ in 1995, and 2,300 g TEQ in 2000. If it is assumed that operations persist for 30 years and the average annual input equals the average over the reference years (2,400 g TEQ), then the cumulative sum would be 72,000 g TEQ. This should be regarded as a preliminary estimate because it is based on numerous assumptions and limited data.

In summary, the total mass of CDD/CDF that is contained in the soil reservoir is approximately 6,150 kg WHO_{98} TEQ with perhaps an additional 170 kg TEQ from past additions (landfills - 61 kg TEQ, pesticide use - 37 kg TEQ and land-applied sludges/ash - 72 kg TEQ). As discussed below, various forms of degradation/removal can occur in soil, which would reduce these contributions from the past, making it uncertain how much of these remain in the soil reservoir today.

11.1.1. Mechanisms Responsible for Releases from Surface Soils

As discussed in the original report, a number of studies have demonstrated that soil releases can occur via erosion, degradation, volatilization, and particle resuspension.

11.1.2. Estimated Annual Releases from Soil to Water

Nonpoint sources of CDD/CDFs to waterways include stormwater runoff from urban areas and soil erosion in rural areas during storms. Approaches for estimating national loadings to water for both of these sources are described below.

11.1.2.1. *Urban Runoff*

No changes were made in this update. As discussed in the original report, a wide range of CDD/CDF concentrations were measured in urban runoff at 23 sites in California (Mathur et al., 1997; Fisher et al., 1999). The midpoint of the 4 order of magnitude range was selected. Based on the wide range of results and uncertainty about the representativeness of the samples, this factor is considered preliminary. The run-off volume was calculated based on rainfall data and urban area data. All factors and release estimates are presented in the release summary below.

11.1.2.2. *Rural Soil Erosion*

The original report also presented estimates for CDD/CDF releases from rural soils. No changes were made to the activity estimates, but updates were made to the emission factors as discussed below.

The data summarized in EPA (2007b) suggest that the typical concentration of CDD/CDFs in soils in rural areas is about 1.7 ng WHO_{98} TEQ_{DF}/kg based on samples from 27 locations. Similarly, EPA (2007b) suggests that the typical concentration of PCBs in soils in rural areas is about 0.07 ng WHO_{98} TEQ_{P}/kg. These values were assumed to apply to all three reference years. It is not known how well these estimates represent eroded soil from cropland and rangeland and were given a preliminary confidence rating. Multiplying the emission factor and activities, yields CDD/CDF release estimates of 4,900, 4,400 and 4,200 g WHO_{98} TEQ_{DF} for 1987, 1995, and 2000, respectively. Similarly, the PCB release estimates were calculated as 200, 180, and 170 g WHO_{98} TEQ_{P} for 1987, 1995, and 2000, respectively. These release estimates have preliminary confidence ratings because the emission factor has a preliminary rating.

11.1.3. Estimated Annual Releases from Soil to Air

As discussed in the original report, a number of investigators have studied releases from soil to air, but no quantitative estimates of the mass of dioxin-like compounds that may be released to the atmosphere annually from U.S. soils have been published in the literature and none were developed for this report. Particulate dioxin concentrations were compared with average total particulate dioxin levels to arrive at the conclusion that soil reentrainment could account for only 1 to 4% of the particulate dioxins in the atmosphere in urban areas and 0.1 to 0.3% of those in rural regions (Kao and Venkataraman, 1995).

The inventory decision criteria and releases to all media are summarized below:

Inventory Decision Criteria for Soil Reservoirs				
	Air	**Water**	**Solids**	**Products**
Emission tests for at least two units/source types with sufficient documentation to directly derive emission factors.	Yes			
Measured emission factors consistent or have understandable differences.	No			
Emission factor tests represent units that are typical of the class.	No			
Activity estimates based on source-specific surveys.	Yes			
Conclusion (Q = Quantitative, P = Preliminary).	P			

Soil Reservoirs
Releases to Air
Not quantifiable.
Releases to Urban Water
Emission Factors • 1987—1 pg WHO$_{98}$ TEQ$_{DF}$/L (1 pg I-TEQ$_{DF}$/L) (Preliminary). • 1995—1 pg WHO$_{98}$ TEQ$_{DF}$/L (1 pg I-TEQ$_{DF}$/L) (Preliminary). • 2000—1 pg WHO$_{98}$ TEQ$_{DF}$/L (1 pg I-TEQ$_{DF}$/L) (Preliminary).
Activity Levels • 1987—1.24×10^{14} L/yr. • 1995—1.33×10^{14} L/yr. • 2000—1.42×10^{14} L/yr.
Releases • 1987—120 g (WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$) (Preliminary). • 1995—130 g (WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$) (Preliminary). • 2000—140 g (WHO$_{98}$ TEQ$_{DF}$ or I-TEQ$_{DF}$) (Preliminary).
Release to Rural Water
Emission Factors • 1987—1.7 ng WHO$_{98}$ TEQ$_{DF}$/kg (Preliminary) and 0.07 ng WHO$_{98}$ TEQ$_{P}$/kg (Preliminary). • 1995—1.7 ng WHO$_{98}$ TEQ$_{DF}$/kg (Preliminary) and 0.07 ng WHO$_{98}$ TEQ$_{P}$/kg (Preliminary). • 2000—1.7 ng WHO$_{98}$ TEQ$_{DF}$/kg (Preliminary) and 0.07 ng WHO$_{98}$ TEQ$_{P}$/kg (Preliminary).
Activity Levels • 1987—2.91 billion MT of soil. • 1995—2.62 billion MT of soil. • 2000—2.46 billion MT of soil.
Releases • 1987—4,900 g WHO$_{98}$ TEQ$_{DF}$ (Preliminary) and 200 g WHO$_{98}$ TEQ$_{P}$ (Preliminary). • 1995—4,500 g WHO$_{98}$ TEQ$_{DF}$ (Preliminary) and 180 g WHO$_{98}$ TEQ$_{P}$ (Preliminary). • 2000—4,200 g WHO$_{98}$ TEQ$_{DF}$ (Preliminary) and 170 g WHO$_{98}$ TEQ$_{P}$ (Preliminary).

11.2. WATER RESERVOIRS (ORIGINALLY SECTION 11.2.2)

As discussed in the original report, water reservoirs have the potential for releases to air or sediment, but no quantifiable estimates could be made.

Water Reservoirs
Releases to Air
Not quantifiable.
Releases to Sediment
Not quantifiable.

11.3. SEDIMENT RESERVOIRS (ORIGINALLY SECTION 11.2.3)

The original report used assumptions about the water surface area, sediment depth, and background TEQ concentration for U.S. sediments to estimate that at least 120 kg WHO_{98} TEQ_{DF} (120 kg I-TEQ_{DF}) are present in the sediment reservoir.

11.3.1. Mechanisms Responsible for Supply to and Releases from Sediment

The original report identified atmospheric deposition of CDDs and CDFs as an important mechanism for CDD/CDFs to enter sediments and those sediments are a likely sink for these compounds because they are strongly bound to organic particles in the sediment.

11.3.2. Releases from Sediment to Water

As discussed in the original report, studies have attempted to evaluate the transfers from sediment to water to air, but the information needed to estimate this release nationally is lacking. For this reason, no quantitative estimates can be made for annual releases from sediment reservoirs to water.

Sediment Reservoirs
Releases to Water
Not quantifiable.

11.4. BIOTA RESERVOIRS (ORIGINALLY SECTION 11.2.4)

CDD/CDFs are found in all types of biota including vegetative matter and animal tissues. No studies were found that estimated the mass of CDD/CDFs in biota in the United States.

11.4.1. Mechanisms Responsible for Supply to and Releases from Biota

The original report identified vapor absorption and desorption as an important mechanism for plants and ingestion/bioaccumulation as an important mechanism for animals.

11.4.2. Approaches for Measuring and Estimating Releases from Biota

The original report describes a number of studies that evaluate the CDD/CDF releases from biota to soil and air, but insufficient information is available to make quantitative estimates for national releases.

Biota Reservoirs
Releases to Air
Not quantifiable.
Releases to Soil
Not quantifiable.

11.5. PRODUCT RESERVOIRS

This is a new section. As discussed in Chapter 8, a number of chemical products contain CDD/CDFs. Some of these can be considered reservoirs because they have the potential for CDD/CDF releases after their initial use. Others are used in a manner such that any releases would occur during their initial use, and therefore, they are not considered a reservoir for future releases. For example, 2,4-D is a pesticide that is applied to foliage and would have an immediate release to biota and soil. Although it may persist in the environment after application, it would become part of the biota or soil reservoir rather than a separate product reservoir. Similarly, chlorobenzenes are used as pesticides or chemical intermediates for pesticides and, therefore, are not considered product reservoirs. The products that may represent potential reservoirs are discussed below.

11.5.1. Bleached Chemical Wood Pulp

The primary discussion of potential dioxin releases from the bleached chemical wood pulp and paper industry is presented in Section 8.1. Many products made from bleached chemical wood pulp remain in use long after their production and, therefore, represent a potential reservoir. The limited data available on the dioxin concentrations in these products indicate decreasing levels over time, but the data are insufficient to make a reliable estimate of the cumulative amounts. As reported in Section 8.1, wood pulp is estimated to have contained 500 g WHO_{98} TEQ in 1987, 40 g WHO_{98} TEQ in 1995, and 0.6 g WHO_{98} TEQ in 2000. The total reservoir of CDD/CDFs in these products would be the cumulative amount of these products remaining in use minus any degradation or releases that have occurred. Insufficient information is available to estimate the size of the total reservoir or the possible releases.

11.5.2. Chlorophenols

The primary discussion of potential dioxin releases from chlorophenol production is presented in Section 8.4. The lower-chlorinated phenols have been used primarily as chemical intermediates in the manufacture of other pesticides. Pesticides are typically used the same year as they are produced and, therefore, are not a reservoir for future releases. The higher-chlorinated phenols (tetrachlorophenol and PCP) and their sodium salts have been used primarily for wood preservation. Wood products treated with these chemicals have long service lives and represent a potential reservoir. As discussed in Chapter 8, an estimate of average annual domestic PCP consumption during the period of 1970 to 1995 is about 400,000 MT. As reported in Section 8.4, PCP is estimated to have contained 20,000 g WHO_{98} TEQ in 1987, 4,800 g WHO TEQ in 1995, and 4,200 g WHO_{98} TEQ in 2000. The limited data available on the dioxin concentrations in these products indicate decreasing levels over time, but the data are insufficient to make a reliable estimate of the cumulative amounts. It is unknown how much of the CDD/CDFs degrade in situ or escapes from the wood into the environment. Several recent field studies, as discussed in Chapter 8, demonstrate that CDD/CDFs do apparently leach into soil from PCP-treated wood, but the studies do not provide release-rate data. No studies were located that provide any measured CDD/CDF volatilization rates from PCP-treated wood. Although CDD/CDFs have very low vapor pressures, they are not bound to, nor do they react with, the wood in any way that would preclude volatilization. Several studies (see Chapter 8) have attempted to estimate potential CDD/CDF volatilization releases using conservative assumptions or modeling approaches, but these estimates span many orders of magnitude. Insufficient information is available to estimate the size of the total reservoir or the possible releases.

11.5.3. Vinyl Chloride Products

The primary discussion of potential dioxin releases from vinyl chloride production is presented in Section 8.3. Many vinyl chloride products remain in use long after their production and, therefore, represent a potential reservoir. Limited data are available on the dioxin concentrations in these products, but the data are insufficient to make a reliable estimate of the cumulative amounts. As discussed in Section 8.3, concentration and production data can be used to estimate that vinyl chloride contained 0.02 g I-TEQ in 1995 and 0.02 g I-TEQ in 2000. The total reservoir of CDD/CDFs in these products would be the cumulative amount of these products remaining in use minus any degradation or releases that have occurred. Insufficient information is available to estimate the size of the total reservoir or the possible releases.

11.5.4. Chloranil

The primary discussion of potential dioxin releases from chloranil production is presented in Section 8.9. Chloranil is used to make dyes and pigments. These products may remain in use long after their production and, therefore, represent a potential reservoir. As discussed in Section 8.9, chloranil imports contained 64 g I-TEQ in 1987, 0.4 g I-TEQ in 1995, and 1.2 g I-TEQ in 2000. The total reservoir of CDD/CDFs in these products would be the cumulative amount of these products remaining in use minus any degradation or releases that have occurred. Insufficient information is available to estimate the size of the total reservoir or the possible releases.

11.5.5. Polychlorinated Biphenyls (PCBs)

As discussed in Chapter 10 (the primary chapter on PCBs), production of PCBs ceased in the 1970s. However, they were used in a variety of products that can remain in use for long time periods, such as transformers and capacitors. The portion of these products that are still in use today represents potential reservoirs because releases can occur via leaks or during disposal operations. As discussed in the original report (see Section 10.6), approximately 568,000 MT of PCBs were used in the United States between 1930 and 1975. An estimated 50.3% were used in capacitors, and 26.8% were used in transformers. Assuming that these products contained an average of 8 mg WHO_{98} TEQ_P/kg (average concentration for Aroclor 1242, which accounted for over 50% of total sales—see Section 10.6 of original report), then a total of 3,500 kg of

WHO_{98} TEQ_P were used in capacitors and transformers. It is unknown how much of this material is still in use or what amount of releases may be occurring.

In summary, five possible product reservoirs were identified: bleached chemical wood pulp, pentachlorophenol, vinyl chloride, chloranil, and PCBs. No estimates could be made for the cumulative mass of CDD/CDFs contained in these reservoirs or their releases.

Product Reservoirs
Releases to Air
Bleached Chemical Wood Pulp (Not quantifiable). Pentachlorophenol (Not quantifiable). Vinylchloride (Not quantifiable). Chloranil (Not quantifiable). PCBs (Not quantifiable).
Releases to Soil
Bleached Chemical Wood Pulp (Not quantifiable). Pentachlorophenol (Not quantifiable). Vinylchloride (Not quantifiable). Chloranil (Not quantifiable). PCBs (Not quantifiable).

11.6. SUMMARY AND CONCLUSIONS (ORIGINALLY SECTION 11.3)

The original report presented a series of conclusions about the relative importance of reservoir sources and their implications to human exposure. Because this version of the document contains only slight revisions to reservoir source estimates, the same general observations made in the previous version still apply. In addition, reservoir sources are all still considered "preliminary", and thus not part of the quantitative inventory.

Table 11-1. Amounts of CDD/CDFs Landfilled (g WHO_{98} TEQ/year)

Source	1987	1995	2000
Municipal waste incinerators	2800	490	490
Medical waste incinerators	760	410	320
Animal crematoria	0.2	0.2	0.2
Sewage sludge	0.4	1	0.7
Industrial wood	46	46	46
Industrial coal-fired utilities	39	43	50
Cement kilns	15	18	13
Magnesium smelting and refining			10[a]
Titanium smelting and refining			240[a]
Chlor-akali plants			3
Vinyl chloride plants			6
Complex organic chemical plants			118
Municipal wastewater treatment sludge	86	40	13
Total	**3,750**	**1,050**	**1,310**

[a]Based on TRI data (U.S. EPA, 2008).

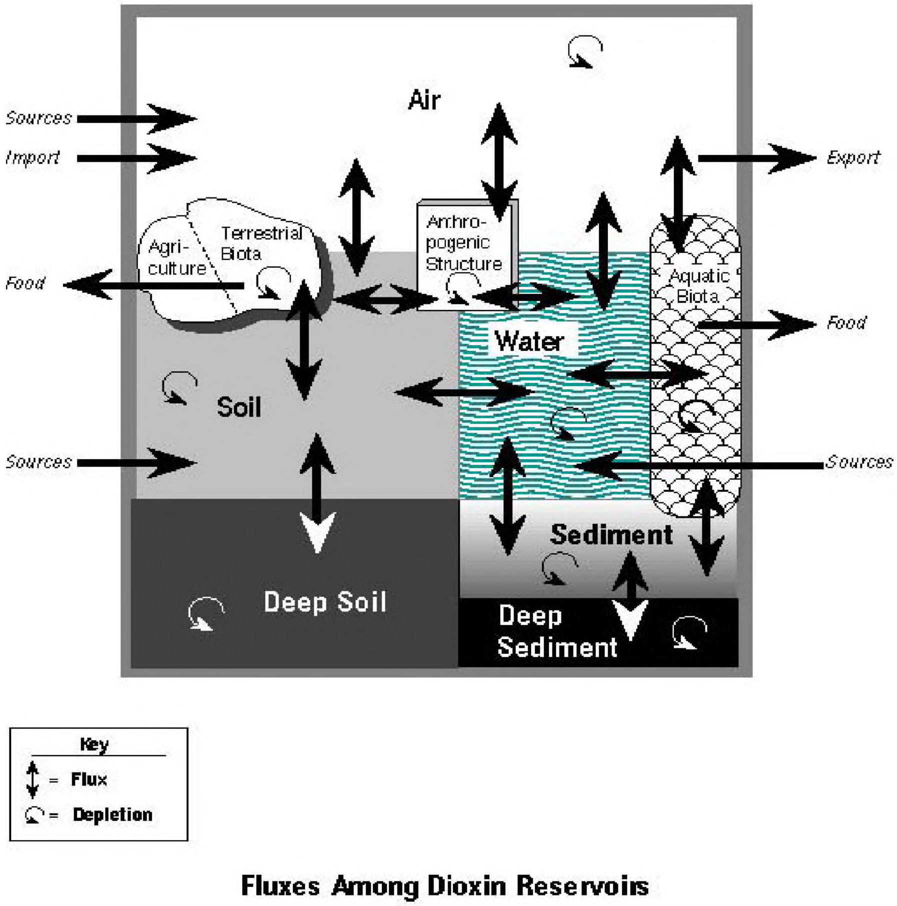

Figure 11-1. Fluxes among environmental reservoirs.

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