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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**

NOTICE

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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-tetrachlorodibenzo-*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<sub>98</sub> TEQ<sub>DF</sub> were 15,000 to air, 2,400 to land, 360 to water, and 36 to products. For 1995, the releases in g WHO<sub>98</sub> TEQ<sub>DF</sub> were 3,400 to air, 2,500 to land, 30 to water, and 47 to products. For 2000, the releases in g WHO<sub>98</sub> TEQ<sub>DF</sub> 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- <i>p</i> -dioxins
BDFs	polybrominated dibenzofurans
Btu	British thermal unit
CARB	California Air Resources Board
CDD	polychlorinated dibenzo- <i>p</i> -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- <i>p</i> -dioxin
HDF	halogenated dibenzofuran
HWI	hazardous waste incinerator
HxCB	hexachlorobiphenyl
IUPAC	International Union of Pure and Applied Chemistry

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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 <sup>3</sup>	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-tetrachlorobideno- <i>p</i> -dioxin
TCDF	2,3,7,8-tetrachlorobidenzofuran
TeCB	tetrachlorobiphenyl

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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

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## 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-tetrachlorodibenzo-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**

<b>Description</b>	<b>2006 Report</b>	<b>Present Report</b>
<b>Air Releases (g WHO<sub>98</sub> TEQ)</b>		
1987	13,500	15,000
1995	3,200	3,400
2000	1,300	2,300
<b>Land Releases (g WHO<sub>98</sub> TEQ)</b>		
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

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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 of 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

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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

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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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub> 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 <sub>98</sub> 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

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- The top three quantified air sources in 2000 were:
  - forest fires (730 g WHO<sub>98</sub> TEQ<sub>DF</sub>),
  - backyard barrel burning of refuse (600 g WHO<sub>98</sub> TEQ<sub>DF</sub>), and
  - medical waste incinerators (400 g WHO<sub>98</sub> TEQ<sub>DF</sub>).
- 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<sub>98</sub> TEQ<sub>DF</sub> to air in 2000), and
  - land clearing debris burning (85 g WHO<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>P</sub> 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<sub>98</sub> TEQ<sub>P</sub> 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

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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<sub>98</sub> 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<sub>98</sub> TEQ<sub>DF</sub>/kg ash) and one for nonrecyclers (620 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg ash). The final emission factor was based on the average of these values (1,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/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<sub>98</sub> TEQ. Combining the activity with the higher emission factor yields a release

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estimate of 2,800 g WHO<sub>98</sub> TEQ. Accordingly the potential range of releases is 740 to 2,800 g WHO<sub>98</sub> TEQ. Relative to the average value (1,900 g WHO<sub>98</sub> 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**

	<b>2006 Report</b>	<b>Present Report</b>	<b>Primary Reason for Change</b>
<b>Air Releases (g WHO<sub>98</sub> TEQ)</b>			
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
<b>Land Releases (g WHO<sub>98</sub> TEQ)</b>			
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

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1 **1. BACKGROUND, APPROACH, AND CONCLUSIONS**

2  
3  
4 **1.1. BACKGROUND**

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

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

22  
23 **1.1.1. Dioxin-Like Compounds**

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

30 The CDDs include 75 individual compounds, CDFs include 135 individual compounds,  
31 and PCBs include 209 individual compounds. These individual compounds are technically  
32 referred to as congeners. 2,3,7,8-tetrachlorodibenzo-*p*-dioxin is the most widely studied (and

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

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

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

26 Table 1-1 provides a complete listing of the chemical nomenclature used in this report.  
27

### 28 **1.1.2. Toxicity Equivalence Factors**

29 CDDs, CDFs, and PCBs are commonly found as complex mixtures when detected in  
30 environmental media, biological tissues, or releases from specific sources. Humans are likely to  
31 be exposed to mixtures of these compounds that vary by source and pathway, complicating the

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1 assessment of human health risk assessment. To address this problem, the concept of a “toxicity  
2 equivalence” (TEQ) has been developed.

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

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

14

$$15 \quad TEQ = \sum_{i=1}^n Concentration_i \times TEF_i \quad (1-1)$$

16

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

21

- 22 • I-TEQ refers to toxic equivalents derived using the international TEF scheme adopted by  
23 EPA in 1989 (U.S. EPA, 1989).
- 24 • WHO<sub>94</sub> TEQ refers to toxic equivalents derived using the 1994 World Health  
25 Organization (WHO) extension of the I-TEF scheme, which includes 13 dioxin-like  
26 PCBs (Ahlborg et al., 1994).
- 27 • WHO<sub>98</sub> TEQ refers to toxic equivalents derived using the 1998 WHO update to the  
28 previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg  
29 et al., 1998).
- 30 • WHO<sub>2005</sub> TEQ refers to toxic equivalents derived using the 2005 WHO update to the  
31 previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg  
32 et al., 2006).

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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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> scheme. If PCBs had also been determined, the nomenclature would be WHO<sub>98</sub> TEQ<sub>DFP</sub>. 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<sub>98</sub> TEF scheme as the primary basis for presenting TEQ estimates. While the WHO<sub>2005</sub> TEFs are more current, the previous version of this document used the WHO<sub>98</sub> TEFs. This document continues the use of the WHO<sub>98</sub> 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.

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

### 16 **1.1.3. Regulatory Summary**

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

### 23 **1.1.4. Information Sources**

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

28           An important reference in this field is the *Standardized Toolkit for Identification and*  
29 *Quantification of Dioxin and Furan Releases* issued by the United Nations Environment  
30 Programme in 2005 (UNEP, 2005). This document was produced to help support  
31 implementation of the Stockholm Convention on Persistent Organic Pollutants. This *Toolkit*

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1 provides a methodology to help countries just developing their inventories to estimate releases of  
2 CDD/CDF and to lead them through the process of enhancing and refining these inventories. It  
3 is intended to provide a consistent basis for assessing CDD/CDF releases over time and between  
4 countries. This updated inventory frequently references the *Toolkit* and discusses the  
5 recommended emission factors.

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

- 12
- 13 • With respect to PCBs, for reporting years 1988–2000, the TRI data are reported as total  
14 PCBs rather than on a congener-specific basis. Thus, it is unknown what portion of these  
15 releases are dioxin-like PCBs, and TEQs cannot be calculated.
- 16 • With respect to CDDs/CDFs, for reporting year 2000, the TRI data are reported as the  
17 sum of the 17 congeners with 2,3,7,8-chlorine-substituted compounds. Facilities had the  
18 option to report an estimate of the congener distribution for total releases, though many  
19 chose not to provide this information. Accordingly, much of the 2000 data could not be  
20 used to make TEQ estimates.
- 21 • The TRI data are self-reported, and facilities are not required to take measurements to  
22 support their emission estimates. Rather, they can be derived from emission factors or  
23 other methods. Facilities are also not required to describe the approach used to make the  
24 emission estimates. Consequently, it would be difficult to evaluate inconsistencies  
25 between these estimates and those in this inventory.
- 26 • The TRI reports include SIC codes but lack further details describing the facilities in  
27 terms of process, production, and pollution controls. Therefore, in many cases, it is not  
28 clear where a reporting facility fits into the classification system used in this report.

## 29

### 30 **1.2. APPROACH**

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

1 **1.2.1. Reference Years**

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

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

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

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

27  
28 **1.2.2. Release Types**

29 A comprehensive assessment of potential dioxin releases from a source requires  
30 consideration of all possible outputs. As diagrammed in Figure 1-1, the outputs of a process can  
31 be in the form of products, air emissions, water discharges, and solid residues. Solid residues

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1 can be used in products, land disposed or incinerated. Each source addressed in this document is  
2 evaluated in terms of all of these outputs. However, not all of the outputs are considered to be  
3 environmental releases. Outputs judged to have a reasonable likelihood for release to the  
4 circulating environment include all air emissions, water discharges, landfarmed wastes and  
5 products which are directly released to the open environment such as some pesticides. Outputs  
6 that are generally not considered an environmental release include waste disposal at lined  
7 landfills, intermediate products or internal waste streams or products containing tightly bound  
8 dioxins such as treated wood. Dioxins contained in some products or disposed in secure landfills  
9 may be released to the circulating environment at some time in the future. They are less likely to  
10 be released to the circulating environment during the same year that they enter into commerce or  
11 are landfilled. Consequently, these contained dioxins would not initially be considered  
12 environmental releases. Ideally, releases derived from such products and landfill practices of  
13 past years would be included in the inventory for the reference year in which the releases occur.  
14 Unfortunately, the current state of science does not support estimating when and to what degree  
15 such releases may occur. However, for informational purposes, and when sufficient information  
16 is available, this document provides estimates of the amount of dioxins contained in products or  
17 disposed in landfills.

### 18 19 **1.2.3. Source Classes**

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

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

27  
28 **1. Combustion.** CDDs/CDFs are formed in most types of combustion. These sources are  
29 addressed in Chapters 3–6:

- 30 • Chapter 3 covers sources involved in waste incineration including municipal solid  
31 waste (MSW), hazardous waste, medical waste, sewage sludge, and other types of  
32 waste.

- 1 • Chapter 4 covers sources related to power/energy generation including motor vehicles  
2 and combustion of wood, oil, and coal.
  - 3 • Chapter 5 covers a variety high temperature sources including cement kilns, asphalt  
4 plants, carbon reactivation furnaces, and others.
  - 5 • Chapter 6 covers minimally controlled or uncontrolled sources and includes landfill  
6 gas flares/fires, forest fires, backyard trash burning in barrels, and others.
- 7 **2. Metals Smelting/Refining.** This category includes sources that are involved in metals  
8 smelting, refining, and processing. They are addressed in Chapter 7.
  - 9 **3. Chemical Manufacturing.** CDDs/CDFs can be formed as by-products in a variety of  
10 chemical manufacturing operations. These are addressed in Chapter 8 and include  
11 chlorine-bleached wood pulp, chlorinated phenols (e.g., pentachlorophenol), PCBs,  
12 chlorobenzenes, phenoxy herbicides (e.g., 2,4-D and 2,4,5-T), and chlorinated aliphatic  
13 compounds (e.g., ethylene dichloride, vinyl chloride, polyvinyl chloride).
  - 14 **4. Biological, Photochemical, and Other Natural Processes.** CDDs/CDFs can form via  
15 biological processes such as the action of microorganisms on chlorinated phenolic  
16 compounds and also during photolysis of highly chlorinated phenols. These are  
17 addressed in Chapter 9.
  - 18 **5. Reservoirs.** Reservoirs are environmental compartments and materials that have the  
19 capacity to store previously formed CDDs/CDFs or dioxin-like PCBs. These compounds  
20 are thus sequestered from the open and circulating environment. Potential reservoirs  
21 include soils, sediments, and biota as well as some anthropogenic materials, such as  
22 PCP-treated utility poles. Dioxin-like compounds in these reservoirs have the potential  
23 for redistribution and circulation in the environment through the physical processes such  
24 as leaching, volatilization, erosion, sedimentation, and deposition. Whenever dioxins are  
25 released from their place of storage back into the circulating environment, the reservoir is  
26 considered a source of dioxin. Reservoirs are addressed in Chapter 11.

27  
28 Note that Chapters 3–9, discussed above, address releases of only CDDs and CDFs.

29 Contemporary formation sources that releases dioxin-like PCBs are discussed in Chapter 10.

30 Reservoir sources that release CDDs, CDFs, or PCBs are covered in Chapter 11.

#### 31 32 **1.2.4. Quantitative Method for Inventory of Sources**

33 Estimates of CDD/CDF releases to the air from individual facilities are derived from  
34 stack testing, which provides the concentration of CDD/CDF in the flue gas. This is combined  
35 with the flue gas flow rate and operating time to estimate annual releases as shown in  
36 equation 1-2:  
37

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

where

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

$C$  = combustion flue gas TEQ concentration (ng/dscm) (20°C, 1 atm; adjusted to 7% O<sub>2</sub>)

$F_v$  = volumetric flow rate of combustion flue gas (dscm/hour) (20°C, 1 atm; adjusted to 7% O<sub>2</sub>)

$CF$  = 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):

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

where

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- 1 EF = emission factor (ng TEQ/kg)
- 2 E<sub>TEQ</sub> = annual TEQ emissions (g/year) (see eq 1-1)
- 3 A = annual activity rate (kg/year)

4

5 A similar approach is used for estimating emission factors for releases to other media.

6 For example, an emission factor for releases to water would involve dividing the annual TEQ

7 release rate via effluent discharges by the annual waste processing rate (or some other measure

8 of activity). The emission factor representing a class of facilities is developed by averaging the

9 emission factors across the tested facilities in the class. This average emission factor is then

10 multiplied by the measure of activity for the nontested facilities in the class (e.g., total kilograms

11 of material processed by these facilities annually). Finally, releases are summed for the tested

12 facilities and nontested facilities. In general, this procedure can be represented by the following

13 equations (eq 1-4 and 1-5):

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

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

18 where

- 19 R<sub>Total</sub> = annual releases from all facilities (g TEQ/year)
- 20 R<sub>Tested, i</sub> = annual releases from all tested facilities in class i (g TEQ/year)
- 21 R<sub>Untested, i</sub> = annual releases from all untested facilities in class i (g TEQ/year)
- 22 EF<sub>Untested, i</sub> = mean emission factor for untested facilities in class i (g TEQ/kg)
- 23 A<sub>i</sub> = activity measure for untested facilities in class i (kg/year)

24

25 Note that even though this approach is presented using the term “emission factor,” it is

26 intended to apply to releases to all media. The method was originally developed for evaluating

27 air emissions and is thus traditionally defined using this term. Also note that for most sources, a

28 small percentage of the facilities had been tested. In these cases, it was not worth the effort to

1 estimate releases from tested and untested facilities separately as shown in equation 1-5. Instead,  
2 the average emission factor was applied to the activity level for the whole class.

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

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

### 26 **1.2.5. Uncertainties**

27 The quantitative inventory has multiple uncertainties, including the following:

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

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

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

12  
13 All of these factors introduce uncertainty into the release estimates. While most of these  
14 uncertainties are impossible to characterize, some can be evaluated as discussed below.

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

- 19  
20 • Classes A, B, and C—Class A indicates high confidence, Class B indicates medium  
21 confidence, and Class C indicates low confidence. These three classes make up the  
22 quantitative inventory.
- 23 • Class D—For many source categories, very limited release data were available and  
24 judged to be inadequate to support development of reliable quantitative release estimates  
25 for one or more media. For some of these source categories, sufficient information was  
26 available, however, to make preliminary estimates of releases. These preliminary  
27 estimates were assigned to Class D.
- 28 • Class E—For other sources, no dioxin release data were available, but either formation  
29 theory or similarity to other sources with measured releases suggested that releases may  
30 occur. These sources were identified to the extent possible, but no release estimates  
31 could be made. They were assigned to Class E.

32  
33 The overall confidence rating assigned to an emissions estimate was determined by the lowest  
34 rating assigned to either the emission factor or activity level.

35 In this update, a revised approach has been developed to characterize the confidence  
36 ratings of the release estimates. The revised approach maintains the three major categories  
37 previously used, i.e., (1) the quantitative inventory [which now includes the sum of the previous

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1 confidence ratings that were subdivided into Class A, B, or C], (2) the preliminary release  
2 estimates [previously assigned a rating of Class D], and the unquantifiable sources [previously  
3 assigned a rating of Class E]. The major changes are the elimination of the Class A, B, or C  
4 confidence distinctions in the quantitative inventory and the addition of the quantitative  
5 uncertainty analysis of the quantitative inventory (presented in Section 1.3.6). The old Class A,  
6 B, and C confidence ratings were eliminated because they were too subjective and difficult to  
7 apply in a consistent fashion. Also, it was judged that confidence ratings for the individual  
8 source classes were less essential because a new quantitative uncertainty analysis has been  
9 added. It was determined that the more important issue was the uncertainty in the total national  
10 release estimate. Accordingly, the new quantitative approach focuses on this issue.

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

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

25 The data used in this document come from hundreds of studies which reported values  
26 using a wide range of significant figures. In the present report, the decision about how many  
27 significant figures to use began with the general policy to report previously published data in the  
28 same manner as in the original publication and to report calculated values with a number of  
29 significant figures no more than the input with the least number of significant figures. This  
30 document reports all emission factors and releases in TEQs. TEQs are derived from toxicity  
31 equivalency factors that are presented with only one significant figure. Although this suggests

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1 that all TEQ estimates should be presented with only one significant figure, they are commonly  
2 reported to 2 or more significant figures in the literature. Limiting the number of significant  
3 figures to 1 for the larger release estimates introduces large rounding adjustments. Therefore, it  
4 was decided to present the release estimates to 2 significant figures when they equal or exceed 10  
5 g TEQ/year. Releases less than 10 g TEQ/year were limited to only 1 significant figure.  
6 Releases less than 0.1 g TEQ/year were presented as <0.1 to reflect the additional uncertainty in  
7 such small estimates and because they have negligible contributions to the total releases.  
8 Similarly the emission factors were reported to 2 significant figures for values that equal or  
9 exceed 0.1 ng TEQ/kg and to 1 significant figure for values less than 0.1 ng TEQ/kg. Activity  
10 estimates are typically very large numbers and are generally known with more certainty than the  
11 emission factors. Therefore, it was decided to report activities to 3 or fewer significant figures.  
12

### 13 **1.3. SUMMARY AND CONCLUSIONS**

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

20 Table 1-13 lists all of the quantitative and preliminary PCB release estimates and  
21 unquantifiable PCB sources. It is organized in the same manner as Table 1-12. Both Tables  
22 1-12 and 1-13 include only contemporary formation sources, i.e., those which form CDD/CDFs  
23 during the same time frame as when the releases occur. Releases can also occur from reservoirs,  
24 which are defined as materials or places that contain previously released CDD/CDFs or dioxin-  
25 like PCBs and have the potential for redistributing these compounds into the environment.  
26 Tables 1-14 (CDD/CDFs) and 1-15 (PCBs) present releases for reservoirs. Releases from  
27 reservoirs are not considered to be part of the official inventory because they are not original  
28 releases but rather the recirculation of past releases.  
29

### 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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub>), backyard barrel burning of refuse (600 g WHO<sub>98</sub> TEQ<sub>DF</sub>), and medical waste incinerators (400 g WHO<sub>98</sub> TEQ<sub>DF</sub>).
- 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<sub>98</sub> TEQ<sub>DF</sub> to air in 2000) and land clearing debris burning (85 g TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>P</sub> 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<sub>98</sub> TEQ<sub>P</sub> for the years 1987, 1995, and 2000, respectively. Also, preliminary estimates could be made for 6 sources,

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1 and 10 sources were identified as being unquantifiable. Although the information is limited, it  
2 suggests that, in terms of TEQs, PCB releases are much lower than CDD/CDF releases.

### 4 **1.3.2. Reservoir Sources**

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

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

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

### 19 **1.3.3. Time Trends**

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

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

1 In terms of total releases from all media, a 67% reduction occurred from 1987 to 1995, a  
2 23% reduction occurred from 1995 to 2000, and a 74% reduction occurred from 1987 to 2000.  
3 Further insight can be gained from examining trends occurring in each medium:

- 4
- 5 • Air—The reductions in total air releases were 85% from 1987 to 2000. Three sources  
6 accounted for over 100% of the reduction: municipal waste incinerators (74%), medical  
7 waste incinerators (18%), and secondary copper smelters (8%). These reductions were  
8 offset by increases in releases from forest fires, which increased by a factor of 4 from  
9 1987 to 2000: 180 g WHO<sub>98</sub> TEQ in 1987 to 730 g WHO<sub>98</sub> TEQ in 2000. Table 1-16  
10 shows that the nonindustrial sources have moved to the top of the rankings.
- 11 • Land—Very little change occurred in land releases over the reference years (4%  
12 reduction in 1987 to 2000). Land release estimates could only be made for  
13 seven sources, and these were dominated by structural fires and backyard barrel burning.
- 14 • Water—Only one source—bleached pulp and paper mills—had water release estimates  
15 for each of the reference years. Thus, the trend analysis is limited to this source. The  
16 reductions from 1987 to 2000 were almost 100% (360 to 1 g WHO<sub>98</sub> TEQ).
- 17 • Product—The reductions in product releases were 81% from 1987 to 2000. Release  
18 estimates could only be made for two products: 2,4-D and land-applied municipal  
19 wastewater treatment sludge. Assuming that dioxins have been eliminated from 2,4-D by  
20 2000 (data are lacking to confirm this), this reduction is virtually 100%. Releases from  
21 sludge actually increased from 1987 to 2000, although the amounts were low (i.e.,  
22 7 g WHO<sub>98</sub> TEQ in 2000).

23

24 One way to assess the validity of these trends is to consider the uncertainties associated with  
25 the release estimates. As discussed in Section 1.3.6 a propagation of error analysis was used to  
26 derive the standard deviation for the air release estimate for the year 2000 based on the top 9  
27 sources (releases = 2,100 g WHO<sub>98</sub> TEQ with SD = 1,300). A similar analysis of the 1987 data  
28 suggests that the air releases (14,000 g WHO<sub>98</sub> TEQ) have an SD of 3,000. This means that the  
29 1987 releases minus two SDs still exceeds the 2000 releases plus two SDs. As a point of  
30 comparison, for normal distributions, 95% of the probability falls within two SDs of the mean.  
31 Although the distribution of possible releases is likely skewed, the large difference between the  
32 total releases and their associated SDs suggest that little overlap occurs between the possible  
33 range of estimates for the 1987 and 2000 releases. Thus the results of this analysis strongly  
34 support the observation of a downward trend.

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

- 7 • Sewage sludge incineration – Baseline estimates for 2010 were 0.4 g WHO<sub>2005</sub> TEQ/yr  
8 with future reductions of 0 g WHO<sub>2005</sub> TEQ/yr (ERG, 2011a). This compares to the  
9 estimates presented here of 10 g WHO<sub>98</sub> TEQ/yr for the year 2000.
- 10 • Medical waste incineration – Baseline estimates for 2008 were 0.83 g WHO<sub>2005</sub> TEQ/yr  
11 with future reductions of 0.66 g WHO<sub>2005</sub> TEQ/yr (Holloway, 2009). This compares to  
12 the estimates presented here of 400 g WHO<sub>98</sub> TEQ/yr for the year 2000.
- 13 • Secondary copper smelting - US EPA concluded that no dioxin emissions occurred from  
14 secondary copper smelting plants in 2006 because all had been shut down (Federal  
15 Register, 2006). This compares to the estimates presented here of 0.9 g WHO<sub>98</sub> TEQ/yr  
16 for the year 2000.
- 17 • Industrial, Commercial, Institutional Boilers and Process Heaters - Baseline estimates for  
18 2008 were 37 g WHO<sub>2005</sub> TEQ/yr with future reductions of 23 g WHO<sub>2005</sub> TEQ/yr  
19 (Singleton and Gibson, 2011). This source category does not match exactly with the  
20 source definitions used here. It includes industrial oil burning boilers (7 g WHO<sub>98</sub>  
21 TEQ/yr for the year 2000) and industrial coal burning boilers (41 g WHO<sub>98</sub> TEQ/yr for  
22 the year 2000)
- 23 • Commercial/Industrial solid waste incineration - Baseline estimates for 2010 were 165 g  
24 total CDD/Fs with future reductions of 115 g total CDD/Fs (ERG, 2011b). Unfortunately  
25 as of press time for the present document, no TEQ conversions were available for these  
26 estimates, making comparisons difficult. Also this source category does not match  
27 exactly with the source definitions used here.

1 **1.3.4. Sources Not Included in the Inventory**

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

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

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

15  
16 **1.3.5. Congener Profiles of CDD/CDF Sources**

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

21  
22 **1.3.6. Uncertainty Analysis**

23 The purpose of this section is to present a quantitative analysis of the uncertainty in the  
24 total release estimates. Given the wide scope of this document (over 80 source categories,  
25 three reference years and four release media), a number of steps were taken to simplify this  
26 analysis. First, it was limited to the 2000 releases because these are the most current. Second, it  
27 was limited to the air and land releases. The releases to the other media are so much smaller,  
28 they will have negligible impact on the overall uncertainty (air—2,300 g WHO<sub>98</sub> TEQ, land—  
29 2,200 g WHO<sub>98</sub> TEQ, water—28 g WHO<sub>98</sub> TEQ and product—7 g WHO<sub>98</sub>-TEQ). Finally, the  
30 number of source categories included in the analyses was limited to the largest ones, with  
31 cumulative contributions of about 90% of the total releases.

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**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 ( $R_i$ ) 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:

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

1 where

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

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

4  $A_i$  = Activity for source i (kg/year)

5

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

17

18 
$$\text{variance in } R_{Total} = \sum_{i=1}^9 \text{variance in } EF_i \times A_i^2 \quad (1-8)$$

19

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

23

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

28

29 
$$EF = 0.5 \left( EF_{field} + EF_{chamber} \right) \quad (1-9)$$

30

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

- 2
- 3 • In 2000, stack tests were available for all operating municipal waste incinerators and  
4 cement kilns burning hazardous waste. The total emissions for these two classes were  
5 estimated by summing the individual emissions from each facility. Thus, an  
6 emission-factor approach based on a subset of the facilities was not necessary. Because  
7 all facilities were tested, in theory, there is no sampling error. However, it is recognized  
8 that factors other than sampling error can contribute to the error in these estimates.  
9 Therefore, the variance for these sources were estimated and included in the propagation  
10 of error calculation.

11

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

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

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

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

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

### 7 **1.3.6.2. Land Releases**

8 The 2000 land releases were dominated by backyard barrel burning which had releases of  
9 1,900 g WHO<sub>98</sub> TEQ (88% of the total) and the uncertainty analysis was limited to this  
10 one source. The releases from backyard barrel burning were based on a study by Lemieux  
11 (1997). Ash samples from the experiments were combined, resulting in two composite samples,  
12 one for recyclers (2,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub> /kg ash) and one for nonrecyclers  
13 (620 ng WHO<sub>98</sub> TEQ<sub>DF</sub> /kg ash). The final emission factor was based on the average of these  
14 values (1,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub> /kg ash). The limited data do not allow a statistical analysis  
15 such as done for the air releases. Instead a potential range of releases was estimated based on the  
16 lower and upper emission factor estimates. The activity estimate for 2,000 was 1.2 MMT.  
17 Combining this value with the lower emission factor yields a release estimate of  
18 740 g WHO<sub>98</sub> TEQ. Combining the activity with the higher emission factor yields a release  
19 estimate of 2,800 g WHO<sub>98</sub> TEQ. Accordingly the potential range of releases is 740 to  
20 2,800 g WHO<sub>98</sub> TEQ. Relative to the average value (1,900 g WHO<sub>98</sub> TEQ), the lower estimate  
21 is 62% less and the upper estimate is 46% more.

### 23 **1.3.7. Relative Impact of Releases**

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

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

<b>Term/symbol</b>	<b>Definition</b>
CDD	Chlorinated dibenzo- <i>p</i> -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**

<b>Compound</b>	<b>I-TEFs</b>	<b>WHO<sub>94</sub></b>	<b>WHO<sub>98</sub></b>	<b>WHO<sub>2005</sub></b>
<b>Chlorinated dibenzo-<i>p</i>-dioxins</b>				
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
<b>Chlorinated dibenzofurans</b>				
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

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

Compound	I-TEFs	WHO <sub>94</sub>	WHO <sub>98</sub>	WHO <sub>2005</sub>
<b>Polychlorinated Biphenyls</b>				
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<sup>a</sup>**

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

<sup>a</sup>Air emission standards promulgated on December 19, 1995.

<sup>b</sup>Large = aggregate capacity  $\geq$ 225 tons/day; small = aggregate capacity <225 tons/day.

<sup>c</sup>ng total CDD/CDF/dscm = nanograms total Cl<sub>4</sub>-Cl<sub>8</sub> CDDs plus CDFs per dry standard cubic meter of stack gas volume, corrected to 7% O<sub>2</sub>.

<sup>d</sup>Began construction on this date.

<sup>e</sup>Modified or upgraded on this date.

<sup>f</sup>When SIPs have been approved by EPA (approximately 3 years from the final rule, or 1998).

<sup>g</sup>For facilities constructed on or before this date.

<sup>h</sup>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<sup>a</sup>**

1

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

<sup>a</sup>Air emission standards promulgated October 12, 2005.

<sup>b</sup>ng I-TEQ/dscm = nanogram I-TEQ per dry standard cubic meter of stack gas volume corrected to 7% O<sub>2</sub>.

APCD = Air pollution control device (dry = dry scrubber or fabric filter).

2 CO = carbon monoxide continuously monitored.

3 HC = Total hydrocarbons continuously monitored.

4 LFB = Liquid fuel boiler.

PM = Particulate matter.

**Table 1-5. Cement kilns not burning hazardous waste<sup>a</sup>**

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

<sup>a</sup>Air emission standards promulgated on June 14, 1999.

<sup>b</sup>ng I-TEQ/dscm = nanograms I-TEQ per dry standard cubic meter of stack gas volume corrected to 7% O<sub>2</sub>.

APCD = Air pollution control device.

PM = Particulate matter.

**Table 1-6. Secondary aluminum smelters<sup>a</sup>**

Process	Emission standard
Sweat furnace	0.8 ng I-TEQ/dscm stack gas corrected to 7% O <sub>2</sub>
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

<sup>a</sup>Air emission standards promulgated on March 23, 2000.

MT = metric ton.

**Table 1-7. Medical waste incinerators<sup>a</sup>**

Category	Existing (ng WHO <sub>2005</sub> TEQ/dscm)	New (ng WHO <sub>2005</sub> TEQ/dscm)
Large	0.054	0.035
Medium	0.020	0.014
Small	0.013	0.013
Small rural	2.1	

<sup>a</sup>Federal Register, 2009.

**Table 1-8. Pulp and paper mills<sup>a</sup>**

1

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

<sup>a</sup>Effluent limitation guidelines promulgated on April 15, 1998.

**Table 1-9. Commercial/Industrial solid waste incinerators<sup>a</sup>**

Category	Existing (ng WHO <sub>2005</sub> TEQ/dscm)	New (ng WHO <sub>2005</sub> 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

<sup>a</sup>Federal Register, 2011a.

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**Table 1-10. Sewage sludge incinerators<sup>a</sup>**

<b>Category</b>	<b>Existing (ng WHO<sub>2005</sub>TEQ/dscm)</b>	<b>New (ng WHO<sub>2005</sub>TEQ/dscm)</b>
Multiple Hearth	0.32	0.0022
Fluidized Bed	0.10	0.0044

<sup>a</sup>Federal Register, 2011b.

**Table 1-11. Industrial, commercial, and institutional boilers and process heaters<sup>a</sup>**

<b>Category</b>	<b>Existing (ng WHO<sub>2005</sub>TEQ/dscm)</b>	<b>New (ng WHO<sub>2005</sub>TEQ/dscm)</b>
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

<sup>a</sup>Federal Register, 2011c.

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**Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO<sub>98</sub> TEQ<sub>DF</sub>/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.
<b>WASTE INCINERATION</b>												
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<sub>98</sub> TEQ<sub>DF</sub>/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							
<b>OTHER HIGH TEMPERATURE SOURCES</b>												
Cement kilns burning hazardous waste												
1987	120				4 <sup>a</sup>				X			
1995	160				4 <sup>a</sup>				X			
2000	19				3 <sup>a</sup>				X			







**Table 1-12. Summary of CDD/CDF releases for reference years 1987, 1995, and 2000 (g WHO<sub>98</sub> TEQ<sub>DF</sub>/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<sub>98</sub> TEQ<sub>DF</sub>/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 <sup>a</sup>										
1995		0.3 <sup>a</sup>										
2000		0.3 <sup>a</sup>										
Copper foundries												
1987	<0.1 <sup>a</sup>											
1995	<0.1 <sup>a</sup>											
2000	<0.1 <sup>a</sup>											
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<sub>98</sub> TEQ<sub>DF</sub>/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
<b>CHEMICAL MANUFACTURING/PROCESSING SOURCES</b>												
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 <sup>a</sup>						2 <sup>a</sup>					
2000	<0.1 <sup>a</sup>						2 <sup>a</sup>					
Stand-alone vinyl chloride plants												
1987												
1995												
2000	0.6 <sup>a</sup>						<0.1 <sup>a</sup>					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<sub>98</sub> TEQ<sub>DF</sub>/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<sub>98</sub> TEQ<sub>DF</sub>/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
<b>TOTALS</b>												
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		

<sup>a</sup>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<sub>98</sub> TEQ<sub>p</sub>/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
<b>METAL REFINING</b>												
Iron ore sintering												
1987		4										
1995		3										
2000		3										
Copper smelting			x									
Aluminum smelting			x									
<b>TOTAL</b>												
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<sub>98</sub> TEQ<sub>DF</sub>)**

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 <sup>a</sup>	
1995			x					4,600 <sup>a</sup>	
2000			x					4,300 <sup>a</sup>	
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

<sup>a</sup>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<sub>98</sub> TEQ<sub>P</sub>)**

Source	Air releases			Land releases			Water releases		
	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ	Q. Inv.	Prelim.	NQ
Soil reservoirs									
1987			x					200 <sup>a</sup>	
1995			x					180 <sup>a</sup>	
2000			x					170 <sup>a</sup>	
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

<sup>a</sup>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.

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**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)
<b>Air</b>	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
<b>Land</b>	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
<b>Water</b>	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<sub>98</sub> TEQ<sub>DF</sub>/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 <sup>a</sup>	64 <sup>b</sup>	0.4 <sup>b</sup>	1.2 <sup>b</sup>
Pentachlorophenol	20,000	4,800	4,200
2,4 -Dichlorophenoxy acetic acid (2,4-D) <sup>a</sup>	33	29	NA
<b>TOTAL</b>	<b>21,000</b>	<b>4,900</b>	<b>4,200</b>

<sup>a</sup>Only 2,4-D is considered to be an environmental release.

<sup>b</sup>Units are I-TEQ.

NA = not available.

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**Table 1-18. Trend analyses based on quantitative inventory<sup>a</sup>**

	Releases (g WHO <sub>98</sub> 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 <sup>b</sup>	360	28	1	-92	-96	-100
Product	36	47	7	+31	-85	-81
Total	18,000	6,000	4,600	-67	-23	-74

<sup>a</sup>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.**

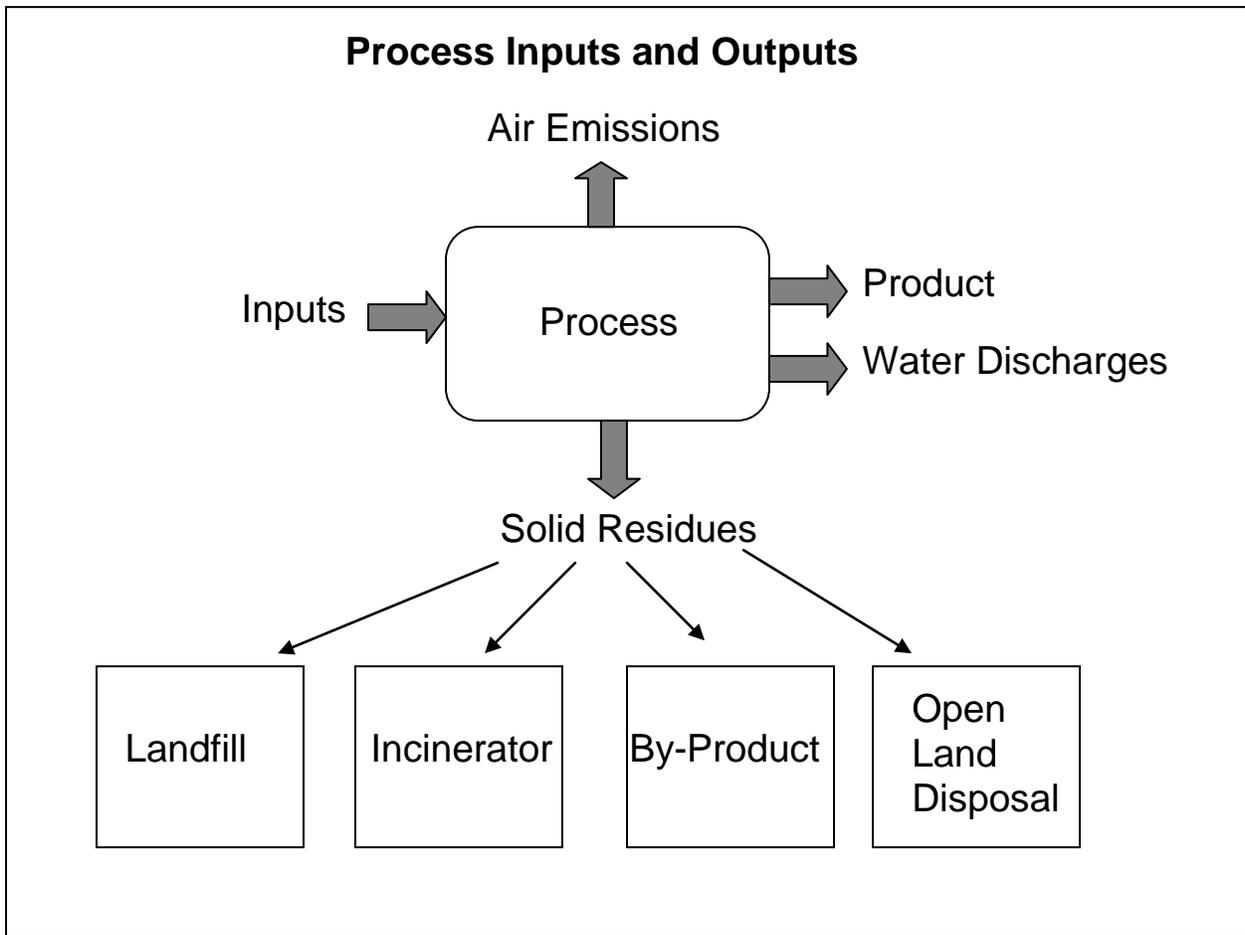
<sup>b</sup>Water releases are based on bleached pulp and paper plants only because this is only source covered in all three reference years.

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

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

<sup>a</sup>Units are L.

<sup>b</sup>Units are pg WHO<sub>98</sub>-TEQ/L.



**Figure 1-1. Process inputs and outputs.**



1           **3. COMBUSTION SOURCES OF CDDS/CDFS: WASTE INCINERATION**

2  
3  
4           **3.1. MUNICIPAL WASTE COMBUSTION**

5           **3.1.1. Air Releases**

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

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

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

- 23
- 24           • Low technology, no APCD—35,000 ng I-TEQ/kg
  - 25           • Controlled, minimal APCD—350 ng I-TEQ/kg
  - 26           • Controlled, good APCD—30 ng I-TEQ/kg
  - 27           • High technology, sophisticated APCD—0.5 ng I-TEQ/kg
- 28

29           The emission factor for controlled facilities with good APCDs (30 ng I-TEQ/kg) was  
30 applied to all small incinerators (defined as those with operating capacities less than 250 tons/day  
31 and totaling 2.6 million tons in 2000), and the emission factor for high technology facilities with  
32 sophisticated APCDs (0.5 ng I-TEQ/kg) was applied to all large facilities (defined as those with

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1 operating capacities greater than 250 tons/day and totaling 27 million tons in 2000). This  
2 approach yields a release estimate of 92 g I-TEQ/year, which is comparable to the  
3 69 g I-TEQ<sub>DF</sub>/year estimate reported here based on adding emissions of each facility.

### 4 5 **3.1.2. Water Releases**

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

### 11 12 **3.1.3. Solid Residue Releases**

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

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

- 24  
25 • Ashes from five state-of-the-art municipal waste combustor facilities located in different  
26 regions of the United States were analyzed for all 2,3,7,8-substituted CDDs/CDFs. The  
27 TEQ levels in the ash (fly ash mixed with bottom ash) ranged from 106 to  
28 466 ng I-TEQ<sub>DF</sub>/kg, with a mean value of 258 ng I-TEQ<sub>DF</sub>/kg CDFs (U.S. EPA, 1990a).
- 29 • Washington State Department of Ecology (1998) reported CDD/CDF congener data for  
30 ash and other solid residuals from three municipal incinerators (Fort Lewis, Bellingham  
31 [municipal plus medical wastes], and Spokane). The data were compiled and evaluated  
32 to determine a total I-TEQ concentration and loading. The results showed fly ash ranging  
33 from 0.51 to 4.98 µg I-TEQ/kg, bottom ash ranging from 0.00 to 0.2 µg I-TEQ/kg, and  
34 mixed ash ranging from 0.038 to 0.163 µg I-TEQ/kg.

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

- 3
- 4 • Kobylecki et al. (2001) analyzed the reduction of dioxins in fly ash by pelletizing the ash  
5 and reburning the pellets in a laboratory-scale bubbling fluidized-bed furnace. Fly ash  
6 for the test input material was collected from a fly ash filter vessel during 4 days of  
7 municipal waste combustor operation. The total TEQ value derived by Kobylecki was  
8 862 ng I-TEQ<sub>DF</sub>/kg of fly ash.
- 9 • Sakai et al. (2001) analyzed the levels of dioxins and PCBs in fly ash and bottom ash  
10 from a newly constructed municipal waste combustor in Japan. TEQ values derived from  
11 the data give a total of 423 ng I-TEQ<sub>DF</sub>/kg for fly ash and 10.5 ng I-TEQ<sub>DF</sub>/kg for bottom  
12 ash for dioxins and 31.6 ng I-TEQ<sub>DF</sub>/kg for fly ash and 0.85 ng I-TEQ<sub>DF</sub>/kg for bottom  
13 ash for PCBs.
- 14

15 UNEP (2005) provided emission factors for fly ash ranging from 15 to 500 µg I-TEQ/MT of  
16 municipal solid waste burned and emission factors for bottom ash ranging from 1.5 to  
17 75 µg I-TEQ/MT of municipal solid waste burned. For municipal waste combustors with  
18 controlled combustion and good APCD (this class would be typical of many of the U.S.  
19 facilities), the recommended values were 200 µg I-TEQ/MT of municipal solid waste burned for  
20 fly ash and 7 µg I-TEQ/MT of municipal solid waste burned for bottom ash.

21 Given the very limited data on TEQ levels in ash from U.S. facilities, it was decided to  
22 use the UNEP (2005) default recommendations as follows: the UNEP recommendations for  
23 municipal waste combustors with controlled combustion and minimal APCDs  
24 (200 µg I-TEQ/MT of municipal solid waste burned for fly ash and 7 µg I-TEQ/MT of municipal  
25 solid waste burned for bottom ash) were assumed to apply to 1987. Extensive improvements in  
26 APCDs (including reductions in the use of hot-sided electrostatic precipitators ESPs) occurred  
27 from 1987 to 1990. So reductions would also be expected in the dioxin content of the ash. Thus,  
28 the UNEP recommendations for municipal waste combustors with controlled combustion and  
29 good APCDs (15 µg I-TEQ/MT of municipal solid waste burned for fly ash and  
30 1.5 µg I-TEQ/MT of municipal solid waste burned for bottom ash) were assumed to apply to  
31 1995 and 2000. These assumptions are summarized below:

- 32 • 1987—200 ng I-TEQ/kg of municipal solid waste burned for fly ash and 7 ng I-TEQ/kg  
33 of municipal solid waste burned for bottom ash

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- 1 • 1995—15 ng I-TEQ/kg of municipal solid waste burned for fly ash and 1.5 ng I-TEQ/kg  
2 of municipal solid waste burned for bottom ash
- 3 • 2000—15 ng I-TEQ/kg of municipal solid waste burned for fly ash and 1.5 ng I-TEQ/kg  
4 of municipal solid waste burned for bottom ash  
5

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

- 8
- 9 • 1987—2,800 g I-TEQ
- 10 • 1995—490 g I-TEQ
- 11 • 2000—490 g I-TEQ  
12

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

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

- 27
- 28 • 1987—The total municipal solid waste burned was estimated as 13.7 billion kg (this  
29 implies that 0.2 billion kg of fly ash and 2.1 billion kg of bottom ash were generated).
- 30 • 1995—The total municipal solid waste burned was estimated as 29.8 billion kg (this  
31 implies that 0.4 billion kg of fly ash and 4.5 billion kg of bottom ash were generated).

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- 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.

<b>Inventory Decision Criteria for Municipal Waste Incinerators</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Municipal Waste Incinerators</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—Table 3-1.</li> <li>• 1995—Table 3-2.</li> <li>• 2000—Table 3-3.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—Table 3-1 (overall total is 13.7 billion kg of waste).</li> <li>• 1995—Table 3-2 (overall total is 29.8 billion kg of waste).</li> <li>• 2000—Table 3-3 (overall total is 29.4 billion kg of waste).</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—Table 3-1. Total releases were 9,500 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (8,500 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 1995—Table 3-2. Total releases were 1,200 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (1,100 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 2000—Table 3-3. Total releases were 77 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (69 g I-TEQ<sub>DF</sub>/yr).</li> </ul>
<b>Water Releases</b>	
Water releases are possible, but data are insufficient to make quantitative estimates (Not quantifiable).	
<b>Solid Residue Releases</b>	
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.	
<b>Products</b>	
Product releases are possible, but data are insufficient to make quantitative estimates (Not quantifiable).	

1 **3.2. HAZARDOUS WASTE INCINERATION**

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

4

5 • Hazardous waste is burned in facilities dedicated to burning this type of waste. Most of  
6 these dedicated facilities are located on site at chemical manufacturing facilities and burn  
7 only the waste associated with their on-site industrial operations. Hazardous waste is also  
8 burned at dedicated facilities located off site. These facilities accept waste from multiple  
9 sources. On- and off-site dedicated hazardous waste burning facilities are addressed in  
10 Section 3.2.1.

11 • Hazardous waste is also burned in industrial boilers and furnaces that are permitted to  
12 burn the waste as supplemental fuel. These facilities have significantly different furnace  
13 designs and operations than those of dedicated hazardous waste incinerators (HWIs).  
14 They are discussed in Section 3.2.2.

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

### 11 **3.2.1. Dedicated HWIs**

#### 12 **3.2.1.1. Air Releases**

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

25 The emission factors were developed using stack test data from a database compiled by  
26 the EPA Office of Solid Waste (OSW). This database summarizes the results of stack testing for  
27 CDDs/CDFs at a number of HWIs between 1993 and 2000 (U.S. EPA, 2002b). For the purposes  
28 of estimating emissions in 1995, an emission factor was developed using data from 17 HWIs  
29 tested between 1993 and 1996. For the purposes of estimating emissions in 2000, an emission  
30 factor was developed using data from 10 HWIs tested in 2000 (a total of 22 HWIs were tested in  
31 2000, but flue gas flow rates were available for only 10 of these incinerators). For the purposes  
32 of estimating emissions in 1987, the emission factor derived for 1995 was assumed to apply to

1 1987. The 1987 activity estimate is from Dempsey and Oppelt (1993), and the 1995/2000  
2 estimate is based on Federal Register (1996).

3 The emission factors assumed here were in the range of 2–4 ng I-TEQ/kg, which falls in  
4 between the values recommended by UNEP (2005) for the top two performing classes:  
5

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

#### 10 11 **3.2.1.2. Water Releases**

12 Many HWIs use wet scrubber systems, which can have water discharges. However, no  
13 information was found to support release estimates (Not quantifiable).  
14

#### 15 **3.2.1.3. Solid Residue Releases**

16 EPA (1987) contains limited data on ash generated from hazardous waste incineration.  
17 The study indicates that the mean concentrations of CDDs and CDFs from an HWI with an  
18 afterburner were 538 µg/kg and 2,853 µg/kg, respectively (Table 3-8 in U.S. EPA, 1987).  
19 Specific data for congeners and for ash quantities were not provided. Accordingly, quantitative  
20 estimates cannot be made about amounts of CDD/CDFs in solid residues from dedicated HWIs.  
21 In the United States, all HWI ash is disposed in permitted landfills. As defined in this inventory,  
22 landfilled material does not represent a true release to the open environment and is not included  
23 in the source inventory.  
24

#### 25 **3.2.1.4. Products—None**

26

1 **3.2.1.5. Release Summary**

2 The inventory decision criteria and releases are summarized below:

<b>Inventory Decision Criteria for Dedicated HWIs</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

<b>Dedicated HWIs</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—3.9 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3.8 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 1995—3.9 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3.8 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 2000—2.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (2.1 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—1.3 billion kg.</li> <li>• 1995—1.5 billion kg.</li> <li>• 2000—1.5 billion kg.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—5 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (5.7 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (3 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).
<b>Solid Residue Releases</b>
Ash is landfilled, so it is not considered an environmental release.
<b>Products</b>
None.

3

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1 **3.2.2. Industrial Boilers and Furnaces Burning Hazardous Waste**

2 **3.2.2.1. Air Releases**

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

13 **3.2.2.2. Water Releases**

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

16

17 **3.2.2.3. Solid Residue Releases**

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

19

20 **3.2.2.4. Products—None**

21

22 **3.2.2.5. Release Summary**

23 The releases are summarized below:

24

1

<b>Inventory Decision Criteria for Industrial Boilers and Furnaces Burning Hazardous Waste</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

<b>Industrial Boilers and Furnaces Burning Hazardous Waste</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.65 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.64 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 1995—0.65 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.64 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 2000—1.2 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.2 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—1.2 billion kg.</li> <li>• 1995—0.6 billion kg.</li> <li>• 2000—0.6 billion kg.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—0.8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.8 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—0.4 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.4 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.7 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

2

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1 **3.2.3. Halogen Acid Furnaces Burning Hazardous Waste**

2 **3.2.3.1. Air Releases**

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

10  
11 **3.2.3.2. Water Releases**

12 No information was found to support release estimates.

13  
14 **3.2.3.3. Solid Residue Releases**

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

16  
17 **3.2.3.4. Products—None**

18  
19 **3.2.3.5. Release Summary**

20 The inventory decision criteria and releases are summarized below:

<b>Inventory Decision Criteria for Halogen Acid Furnaces Burning Hazardous Waste</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Halogen Acid Furnaces Burning Hazardous Waste</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.84 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.80 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 1995—0.84 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.80 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> <li>• 2000—0.84 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.80 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—376 million kg.</li> <li>• 1995—376 million kg.</li> <li>• 2000—376 million kg.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.3 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.3 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.3 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>	
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

1 **3.3. MEDICAL WASTE INCINERATION**

2 **3.3.1. Air Releases**

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

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

15

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

### 5 **3.3.2. Water Releases**

6 Some medical waste incinerators use wet scrubber systems, which can have water  
7 discharges. However, no information was found to support release estimates (Not quantifiable).  
8

### 9 **3.3.3. Solid Residue Releases**

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

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

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

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

- 3
- 4 • 1987—760 g I-TEQ<sub>DF</sub>
- 5 • 1995—410 g I-TEQ<sub>DF</sub>
- 6 • 2000—320 g I-TEQ<sub>DF</sub>
- 7

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

10 The total amount of landfilled ash is not directly used in the calculation above. However,  
 11 it may be of interest and is provided below for information purposes only. The estimates were  
 12 generated by assuming that the combined fly and bottom equals 20% of the waste feed (UNEP,  
 13 2005). This yields the following estimates:

- 14 • 1987—0.28 billion kg
- 15 • 1995—0.15 billion kg
- 16 • 2000—0.12 billion kg
- 17

18 **3.3.4. Products—None**

19

20 **3.3.5. Release Summary**

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

<b>Inventory Decision Criteria for Medical Waste Incinerators</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Medical Waste Incinerators</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—Table 3-4.</li> <li>• 1995—Table 3-4.</li> <li>• 2000—Table 3-4.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—Table 3-4.</li> <li>• 1995—Table 3-4.</li> <li>• 2000—Table 3-4.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—2,700 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (2,600 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 1995—510 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (490 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 2000—400 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (380 g I-TEQ<sub>DF</sub>/yr).</li> </ul>
<b>Water Releases</b>	
Possible, but data are insufficient to make quantitative estimates (Not quantifiable).	
<b>Solid Residue Releases</b>	
The ash is landfilled so it is not considered an environmental release.	
<b>Products</b>	
None.	

1 **3.4. CREMATORIA**

2 **3.4.1. Human Crematoria**

3 **3.4.1.1. Air Releases**

4 No changes were made to the air-release estimates. The emission factor was derived on  
5 the basis of testing at two U.S. facilities and assumed to apply to all reference years. It  
6 corresponds to the low end of the range recommended by UNEP (2005):  
7 400 ng I-TEQ/cremation for facilities with optimal control, 10,000 ng I-TEQ/cremation for  
8 facilities with medium control, and 90,000 ng I-TEQ/cremation for facilities with no control.  
9 Activity information was derived from CANA (2006).

10

1 **3.4.1.2. *Water Releases***

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

4  
5 **3.4.1.3. *Solid Residue Releases***

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

8 UNEP (2005) recommends an ash emission factor of 2,500 ng I-TEQ/cremation for  
9 facilities with medium or optimal control. The CDD/CDF concentrations in the bottom ashes  
10 collected from a two-chamber crematory in Thailand were 44 and 48 ng I-TEQ/kg of bottom ash  
11 (UNEP, 2005; Fiedler et al., 2002). Based on the average of these tests, a concentration of  
12 46 ng I-TEQ/kg of bottom ash is assumed for each reference year. This facility appears to have a  
13 similar design to U.S. facilities. However, the emission factor was assigned a preliminary rating  
14 because it is based on testing at only one facility.

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

18

- 19 • 1987—1.24 million kg
- 20 • 1995—1.88 million kg
- 21 • 2000—2.42 million kg

22

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

25 **3.4.1.4. *Products—None***

26

27 **3.4.1.5. *Release Summary***

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

<b>Inventory Decision Criteria for Human Crematoria</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Human Crematoria</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—450 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/body cremated (430 ng I-TEQ<sub>DF</sub>/body cremated).</li> <li>• 1995—450 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/body cremated (430 ng I-TEQ<sub>DF</sub>/body cremated).</li> <li>• 2000—450 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/body cremated (430 ng I-TEQ<sub>DF</sub>/body cremated).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—A total of 323,371 cremations were performed.</li> <li>• 1995—A total of 488,224 cremations were performed.</li> <li>• 2000—A total of 629,362 cremations were performed.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—0.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.1 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—0.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.2 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.3 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—46 ng I-TEQ/kg of ash (Preliminary).</li> <li>• 1995—46 ng I-TEQ/kg of ash (Preliminary).</li> <li>• 2000—46 ng I-TEQ/kg of ash (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—1.24 million kg ash.</li> <li>• 1995—1.88 million kg ash.</li> <li>• 2000—2.42 million kg ash.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—0.1 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—0.1 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—0.1 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Products</b>
None.

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1 **3.4.2. Animal Crematoria**

2 **3.4.2.1. Air Releases**

3 Minor changes were made in how these air releases were estimated. For destruction of  
4 animal carcasses, UNEP (2005) recommends emission factors of 5 ng I-TEQ/kg for state-of-the-  
5 art facilities, 50 ng I-TEQ/kg for updated facilities, and 500 ng I-TEQ/kg for uncontrolled  
6 facilities. As described in EPA, 2006, only one U.S. facility emission test could be located. This  
7 facility had very low emissions and may not be representative of most facilities. The mid-range  
8 value recommend by UNEP was judged to more likely represent typical U.S. facilities.

9 Therefore, this emission factor was assumed to apply to each of the reference years:

10 50 ng I-TEQ<sub>DF</sub>/kg of animal cremated. Based on the limited test data and questions about its  
11 representativeness, this emission factor is considered a preliminary estimate.

12 As part of the 2000 inventory, OAQPS (U.S. EPA, 2002b) calculated a national animal  
13 cremation activity level estimate of 81.9 million kg/year for reference year 2000. Assuming that  
14 the fraction of the population owning pets and the fraction of pets cremated stay reasonably  
15 constant, this value can be extrapolated to the other reference years by assuming that animal  
16 cremation rates are proportional to the human population. The following U.S. population  
17 estimates were used in this exercise: 1987—242 billion, 1995—263 billion, and  
18 2000—291 billion. The data for each reference year are presented below:

19

- 20 • 1987—68 million kg/year.
- 21 • 1995—74 million kg/year
- 22 • 2000—81.9 million kg/year

23

24 **3.4.2.2. Water Releases—None**

25

26 **3.4.2.3. Solid Residue Releases**

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

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1 As indicated above, emission testing data could be located for only one facility. No  
2 bottom ash testing was reported for this facility. It has a similar design to the human cremation  
3 facility in Thailand where testing found 44 and 48 ng I-TEQ/kg of bottom ash (UNEP, 2005;  
4 Fiedler et al., 2002). Based on the average of these tests, an bottom ash concentration of  
5 46 ng I-TEQ/kg is assumed for all reference years. It is completely unknown how representative  
6 this facility is of U.S. facilities. Accordingly, it must be regarded as preliminary.

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

- 10
- 11 • 1987—3.7 million kg
- 12 • 1995—4.1 million kg
- 13 • 2000—4.5 million kg
- 14

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

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

- 19
- 20 • 1987—0.17 g I-TEQ<sub>DF</sub> (Preliminary)
- 21 • 1995—0.19 g I-TEQ<sub>DF</sub> (Preliminary)
- 22 • 2000—0.21 g I-TEQ<sub>DF</sub> (Preliminary)
- 23

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

#### 26

#### 27 **3.4.2.4. Products—None**

#### 28

#### 29 **3.4.2.5. Release Summary**

30 The inventory decision criteria and releases are summarized below:

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<b>Inventory Decision Criteria for Animal Crematoria</b>	
	<b>Air    Water    Solids    Products</b>
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

<b>Animal Crematoria</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—50 ng I-TEQ<sub>DF</sub>/kg of animal cremated (Preliminary).</li> <li>• 1995—50 ng I-TEQ<sub>DF</sub>/kg of animal cremated (Preliminary).</li> <li>• 2000—50 ng I-TEQ<sub>DF</sub>/kg of animal cremated (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—68 million kg/yr.</li> <li>• 1995—74 million kg/yr.</li> <li>• 2000—81.9 million kg/yr.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—3 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—4 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—4 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
This ash is landfilled and, therefore, is not considered an environmental release.
<b>Products</b>
None.

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1 **3.5. SEWAGE SLUDGE INCINERATION**

2 **3.5.1. Air Releases**

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

9

10 **3.5.2. Water Releases**

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

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

24 The European inventory (EU, 1999) reports concentrations between 1.2 and  
25 6.5 pg I-TEQ/L in scrubber effluents from sewage sludge incinerators.

26

27 **3.5.3. Solid Residue Releases**

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

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

7 In Table 5-16 of EPA (1987), data are presented indicating that 2,3,7,8-TCDD was not  
8 detected in the bottom ash from three sewage sludge incinerators. However, total CDDs for the  
9 three incinerators were nondetects, 20 ng/kg, and 10 ng/kg. For total CDFs, the values were  
10 nondetects, 70 ng/kg, and 50 ng/kg. No data were given for any congeners (other than  
11 2,3,7,8-TCDD), nor were there any data on the quantities of ash.

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

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

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

- 20
- 21 • 1987—0.43 g I-TEQ<sub>DF</sub> (Preliminary)
  - 22 • 1995—1.0 g I-TEQ<sub>DF</sub> (Preliminary)
  - 23 • 2000—0.71 g I-TEQ<sub>DF</sub> (Preliminary)
- 24

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

27

#### 28 **3.5.4. Products—None**

29

1 **3.5.5. Release Summary**

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

<b>Inventory Decision Criteria for Sewage Sludge Incinerators</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

<b>Sewage Sludge Incinerators</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—6.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (6.6 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—6.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (6.6 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—6.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (6.6 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.865 billion kg of dry sewage sludge.</li> <li>• 1995—2.11 billion kg of dry sewage sludge.</li> <li>• 2000—1.42 billion kg of dry sewage sludge.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (6 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—14 g WHO<sub>98</sub> TEQ<sub>DF</sub> (14 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—10 g WHO<sub>98</sub> TEQ<sub>DF</sub> (9 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
Possible but quantitative releases could not be made (Not quantifiable).	
<b>Solid Residue Releases</b>	
The ash from these facilities is assumed to be landfilled and, therefore, is not considered a release to the open environment.	
<b>Products</b>	
None.	

3

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1 **3.6. TIRE COMBUSTION**

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

10  
11 **3.6.1. Air Releases**

12 No changes were made to the air-release estimates. The emission factor of 0.28 ng  
13 WHO<sub>98</sub> TEQ<sub>DF</sub>/kg was derived from testing at one facility that was equipped with a dry scrubber  
14 and fabric filter (CARB, 1991). Because other facilities may be equipped with less sophisticated  
15 air pollution control systems, the TEQ emissions could be higher. For example, Cains and Dyke  
16 (1994) reported much higher emission rates for two tire incinerators in the United Kingdom that  
17 were equipped with only simple grit arrestors. Because the emission factor is based on testing at  
18 only one facility and it is inconsistent with other data, the release estimate is considered  
19 preliminary. The activity estimates were derived from survey data from EPA, (1992b) and  
20 Rubber Manufacturers Association (RMA) (2002).

21  
22 **3.6.2. Water Releases**

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

27  
28 **3.6.3. Solid Residue Releases**

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

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**3.6.4. Products—None**

**3.6.5. Release Summary**

The inventory decision criteria and releases are summarized below:

<b>Inventory Decision Criteria for Tire Combustion</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

<b>Tire Combustion</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—0.28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.28 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> <li>• 1995—0.28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.28 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> <li>• 2000—0.28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.28 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—0.385 billion kg.</li> <li>• 1995—0.385 billion kg.</li> <li>• 2000—1.8 billion kg.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (0.1 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> <li>• 1995—0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (0.1 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> <li>• 2000—0.5 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (0.5 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> </ul>
<b>Water Releases</b>
Possible but quantitative releases could not be made (Not quantifiable).
<b>Solid Residue Releases</b>
Ash generated at these facilities is landfilled and, therefore, not considered an environmental release.
<b>Products</b>
None.

1 **3.7. COMBUSTION OF WASTEWATER SLUDGE AT BLEACHED CHEMICAL**  
2 **PULP MILLS**

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

10  
11

1 **3.8. BIOGAS COMBUSTION**

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

<b>Inventory Decision Criteria for Biogas Combustion</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Biogas Combustion</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—0.46 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> of digester gas combusted (Preliminary).</li> <li>• 1995—0.46 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> of digester gas combusted (Preliminary).</li> <li>• 2000—0.46 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> of digester gas combusted (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—467-million Nm<sup>3</sup> (Preliminary).</li> <li>• 1995—467-million Nm<sup>3</sup> (Preliminary).</li> <li>• 2000—467-million Nm<sup>3</sup> (Preliminary).</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—0.2 g I-TEQ<sub>DF</sub>/yr (Preliminary).</li> <li>• 1995—0.2 g I-TEQ<sub>DF</sub>/yr (Preliminary).</li> <li>• 2000—0.2 g I-TEQ<sub>DF</sub>/yr (Preliminary).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
None.
<b>Products</b>
None.

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>H-ESP subtotals</b>					<b>5.20E+09</b>			<b>2,450</b>	<b>2,740</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
MBWW DS/FF	19	Marion Co.	Brooks	OR	1.55E+08	0.67	0.72	0.1	0.1
<b>DS/FF subtotals</b>					<b>1.55E+08</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals For Mass Burn Waterwall</b>					<b>5.35E+09</b>			<b>2,450</b>	<b>2,740</b>
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	
<b>H-ESP subtotals</b>					<b>2.00E+09</b>			<b>945</b>	<b>1,100</b>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>WS subtotals</b>					<b>9.01E+08</b>			<b>212</b>	<b>229</b>
MB/REF DS/FF	39	Framingham	Framingham	MA	1.41E+08	0.67	0.72	0.1	0.1
<b>DS/FF subtotals</b>					<b>1.41E+08</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals For Mass Burn Refractory</b>					<b>3.04E+09</b>			<b>1,160</b>	<b>1,330</b>
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	
<b>H-ESP subtotals</b>					<b>4.37E+08</b>			<b>33</b>	<b>36</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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	Harpwell	Harpwell	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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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	
<b>UNC subtotals</b>					<b>5.17E+08</b>			<b>8.5</b>	<b>8.9</b>
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
<b>WS subtotals</b>					<b>5.30E+07</b>			<b>0.8</b>	<b>0.8</b>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>FF subtotals</b>					<b>1.43E+08</b>			<b>2.3</b>	<b>2.5</b>
<b>Totals For Modular-Starved Air</b>					<b>1.15E+09</b>			<b>44</b>	<b>48</b>
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
<b>UNC subtotals</b>					<b>4.17E+07</b>			<b>0.7</b>	<b>0.7</b>
MOD/EA WS	95	East Chicago	East Chicago	IN	1.27E+08	16.2	17	2.1	2.2
<b>WS subtotals</b>					<b>1.27E+08</b>			<b>2.1</b>	<b>2.2</b>
MOD/EA EGB	96	Pittsfield	Pittsfield	MA	6.76E+07	0.67	0.72	0.1	0.1
<b>EGB subtotals</b>					<b>6.76E+07</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals For Modular Excess Air</b>					<b>2.36E+08</b>			<b>2.8</b>	<b>2.9</b>
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
<b>H-ESP subtotals</b>					<b>1.41E+08</b>			<b>33</b>	<b>33</b>
<b>Totals For Refuse Derived Fuel Cofired With Coal</b>					<b>1.41E+08</b>			<b>33</b>	<b>33</b>
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

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3-37 DRAFT: DO NOT CITE OR QUOTE

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
	105	Columbus	Columbus	OH	5.63E+08	Actual tested stack emissions		840	946
<b>H-ESP subtotals</b>					<b>3.01E+09</b>			<b>4,490</b>	<b>5,060</b>
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
<b>WS subtotals</b>					<b>3.38E+08</b>			<b>80</b>	<b>82</b>
<b>Totals for refuse-derived fuel—dedicated</b>					<b>3.49E+09</b>			<b>4570</b>	<b>5140</b>
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
<b>H-ESP subtotals</b>					<b>3.94E+08</b>			<b>189</b>	<b>210</b>
MB/RK FF	111	Galax	Galax	VA	1.58E+07	47	93.1	0.7	1.5
<b>FF subtotals</b>					<b>1.58E+07</b>			<b>0.7</b>	<b>1.5</b>
<b>Totals for mass burn rotary kiln</b>					<b>4.10E+08</b>			<b>190</b>	<b>212</b>
<b>TOTALS FOR ALL MWCs operating in 1987</b>					<b>1.37E+10</b>			<b>8450</b>	<b>9510</b>

1/7/2013

*This document is a draft for review purposes only and does not constitute Agency policy.*  
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**Table 3-1. Inventory of municipal waste combustors (MWCs) in 1987 (continued)**

<sup>a</sup>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).

<sup>b</sup>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.

<sup>c</sup>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.

<sup>d</sup>The I-TEQ<sub>DF</sub> Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

<sup>e</sup>The WHO<sub>98</sub> TEQ<sub>DF</sub> Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>DS/FF subtotals</b>					<b>9.13E+09</b>			<b>6.3</b>	<b>6.8</b>
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
<b>C-ESP subtotals</b>					<b>2.81E+09</b>			<b>17</b>	<b>18</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>DS/C-ESP subtotals</b>					<b>2.73E+09</b>			<b>13</b>	<b>15</b>
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
<b>DSI/FF subtotals</b>					<b>1.97E+08</b>			<b>0.5</b>	<b>0.5</b>
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
<b>DS/CI/FF subtotals</b>					<b>1.17E+09</b>			<b>1.7</b>	<b>1.9</b>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>H-ESP subtotals</b>					<b>1.04E+09</b>			<b>249</b>	<b>279</b>
MB/WW DSI/H-ESP	57	North Andover	North Andover	MA	4.22E+08	Actual tested stack emissions		3.3	3.5
<b>DSI/H-ESP subtotals</b>					<b>4.22E+08</b>			<b>3.3</b>	<b>3.5</b>
MB/WW DSI/CI/H-ESP	58	Alexandria RRF	Alexandria	VA	2.75E+08	Actual tested stack emissions		2.1	2.3
<b>DSI/CI/H-ESP subtotals</b>					<b>2.75E+08</b>			<b>2.1</b>	<b>2.3</b>
<b>Totals for mass burn waterwall</b>					<b>1.74E+10</b>			<b>293</b>	<b>327</b>
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
<b>Subtotals for MB/REF WS</b>					<b>2.04E+08</b>			<b>48</b>	<b>52</b>
MB/REF DS/C-ESP	61	Pulaski	Baltimore	MD	4.22E+08	Actual tested stack emissions		22	22
<b>DS/C-ESP subtotals</b>					<b>4.22E+08</b>			<b>22</b>	<b>22</b>
MB/REF C-ESP	62	Clinton	Clinton	MI	1.69E+08	Actual tested stack emissions		40	43
<b>C-ESP subtotals</b>					<b>1.69E+08</b>			<b>40</b>	<b>43</b>
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
<b>DS/FF subtotals</b>					<b>2.67E+08</b>			<b>0.1</b>	<b>0.2</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
MB/REF DSI/FF	65	Davis Co.	Layton	UT	1.13E+08	1.91	2.07	0.2	0.2
<b>DSI/FF subtotals</b>					<b>1.13E+08</b>			<b>0.2</b>	<b>0.2</b>
<b>Totals for mass burn refractory</b>					<b>1.18E+09</b>			<b>110</b>	<b>117</b>
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
<b>MB/RK C-ESP subtotals</b>					<b>2.00E+08</b>			<b>9.5</b>	<b>18</b>
MB/RK DSI/C-ESP	68	Dayton RRF	Dayton	OH	5.07E+08	47	93.1	24	47
<b>DSI/C-ESP subtotals</b>					<b>5.07E+08</b>			<b>24</b>	<b>47</b>
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
<b>DSI/FF subtotals</b>					<b>2.59E+08</b>			<b>12</b>	<b>24</b>
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
<b>DS/FF subtotals</b>					<b>1.14E+09</b>			<b>0.7</b>	<b>0.8</b>
<b>Totals for mass burn rotary kiln</b>					<b>2.10E+09</b>			<b>46</b>	<b>90</b>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
<b>RDF/ded C-ESP subtotals</b>					<b>1.81E+09</b>			<b>422</b>	<b>458</b>
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
<b>DS/C-ESP subtotals</b>					<b>1.75E+09</b>			<b>0.9</b>	<b>0.9</b>
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
<b>DS/FF subtotals</b>					<b>3.07E+09</b>			<b>0.7</b>	<b>0.8</b>
RDF/ded DSI/FF	88	Elk River RRF	Elk River	MN	4.22E+08	47	93.1	20	39
<b>DSI/FF subtotals</b>					<b>4.22E+08</b>			<b>20</b>	<b>39</b>
RDF/ded DSI/H-ESP	89	Haverhill Lawrence	Lawrence	MA	2.00E+08	285	316	57	63
<b>DSI/H-ESP subtotals</b>					<b>2.00E+08</b>			<b>57</b>	<b>63</b>
RDF/ded H-ESP	90	Kodak MWC	Rochester	NY	4.22E+07	1,490	1,680	63	71
<b>H-ESP subtotals</b>					<b>4.22E+07</b>			<b>63</b>	<b>71</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
<b>Totals for dedicated refuse derived fuel</b>					<b>7.30E+09</b>			<b>564</b>	<b>633</b>
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
<b>UNC subtotals</b>					<b>1.87E+08</b>			<b>3.1</b>	<b>3.1</b>
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
<b>H-ESP subtotals</b>					<b>1.81E+08</b>			<b>14</b>	<b>16</b>
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
<b>C-ESP subtotals</b>					<b>1.25E+08</b>			<b>2.0</b>	<b>2.2</b>

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

Design <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
MOD/SA DS/DSI/C-ESP	108	Chamber Medical	Hampton	SC	7.60E+07	16.2	17	1.2	1.3
<b>DS/DSI/C-ESP subtotals</b>					<b>7.60E+07</b>			<b>1.2</b>	<b>1.3</b>
MOD/SA DSI/FF	109	St. Croix WTE	New Richmond	WI	2.87E+07	0.02	0.03	<0.1	<0.1
<b>DSI/FF subtotals</b>					<b>2.87E+07</b>			<b>&lt;0.1</b>	<b>&lt;0.1</b>
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
<b>WS subtotals</b>					<b>4.90E+07</b>			<b>0.8</b>	<b>0.9</b>
MOD/SA WS/FF	113	Recomp Bellingham	Bellingham	WA	2.82E+07	16.2	17	0.5	0.5
<b>WS/FF subtotals</b>					<b>2.82E+07</b>			<b>0.5</b>	<b>0.5</b>
<b>Totals for modular-starved air</b>					<b>6.46E+08</b>			<b>22</b>	<b>24</b>
MOD/EA UNC	114	Mayport NAS	Mayport	FL	1.41E+07	16.2	17	0.2	0.2
<b>UNC subtotals</b>					<b>1.41E+07</b>			<b>0.2</b>	<b>0.2</b>
MOD/EA H-ESP	115	Richards Asphalt Co.	Savage	MN	1.97E+07	Actual tested stack emissions		2.3	2.4
<b>H-ESP subtotals</b>					<b>1.97E+07</b>			<b>2.3</b>	<b>2.4</b>
MOD/EA DSI/H-ESP	116	Sitka MWC	Sitka	AK	1.41E+07	118	119	1.7	1.7
<b>DSI/H-ESP subtotals</b>					<b>1.41E+07</b>			<b>1.7</b>	<b>1.7</b>
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 <sup>a</sup> class APCD <sup>b</sup>		Facility name	City located	State	Activity level <sup>c</sup> (kg/y)	I-TEQ EF <sup>d</sup> (ng/kg)	WHO TEQ EF <sup>e</sup> (ng/kg)	Annual air emissions (g/y)	
								I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
	119	Pascagoula RRF	Moss Point	MS	4.22E+07	16.2	17	0.7	0.7
<b>C-ESP subtotals</b>					<b>8.28E+07</b>			<b>1.1</b>	<b>1.1</b>
MOD/EA DS/FF	120	Wallingford RRF	Wallingford	CT	1.18E+08	16.2	17	1.9	2.0
<b>DS/FF subtotals</b>					<b>1.18E+08</b>			<b>1.9</b>	<b>2.0</b>
MOD/EA DSI/FF	121	Springfield RRF	Agawam	MA	1.01E+08	16.2	17	1.6	1.7
<b>DSI/FF subtotals</b>					<b>1.01E+08</b>			<b>1.6</b>	<b>1.7</b>
MOD/EA WS/C-ESP	122	Pittsfield RRF	Pittsfield	MA	6.76E+07	Actual tested stack emissions		1.1	1.2
<b>WS/C-ESP subtotals</b>					<b>6.76E+07</b>			<b>1.1</b>	<b>1.2</b>
<b>Totals for modular excess air</b>					<b>4.17E+08</b>			<b>10</b>	<b>10</b>
FB/RDF DS/FF	123	Fayetteville RRF	Fayetteville	NC	1.69E+08	0.67	0.72	0.1	0.1
<b>DS/FF subtotals</b>					<b>1.69E+08</b>			<b>0.1</b>	<b>0.1</b>
FB/RDF DSI/FF	124	Tacoma RRF	Tacoma	WA	8.45E+07	0.67	0.72	0.1	0.1
<b>DSI/FF subtotals</b>					<b>8.45E+07</b>			<b>0.1</b>	<b>0.1</b>
FB/RDF DSI/EGB	125	LaCrosse Co.	La Crosse	WI	1.13E+08	Actual tested stack emissions		0.1	0.1
<b>DSI/EGB subtotals</b>					<b>1.13E+08</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals for fluidized bed/refuse-derived fuel</b>					<b>3.66E+08</b>			<b>0.3</b>	<b>0.3</b>
<b>Totals for all MWCs operating in 1995</b>					<b>2.98E+10</b>			<b>1050</b>	<b>1200</b>

<sup>a</sup>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).

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<sup>b</sup>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.

<sup>c</sup>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.

<sup>d</sup>The I-TEQ<sub>DF</sub> Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

<sup>e</sup>The WHO<sub>98</sub> TEQ<sub>DF</sub> Emission Factor (EF) expressed in units of ng TEQ/kg combusted.

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

Design <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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 <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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	
	<b>DS/FF/CI/SNCR subtotals</b>				<b>1.34E+10</b>			<b>2.3</b>	<b>2.5</b>
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
		<b>DS/FF/SNCR subtotals</b>				<b>2.99E+09</b>			<b>0.9</b>
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
		<b>DS/FF/CI subtotals</b>				<b>1.25E+08</b>			<b>0.2</b>
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
		<b>DS/FF subtotals</b>				<b>1.88E+08</b>			<b>&lt;0.1</b>

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

Design <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
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
<b>DS/ESP/CI/SNCR subtotals</b>					<b>2.79E+09</b>			<b>1.3</b>	<b>1.3</b>
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
	<b>DS/ESP/CI subtotals</b>					<b>3.74E+08</b>			<b>1.3</b>
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
	<b>C-ESP subtotals</b>					<b>4.99E+08</b>			<b>3.1</b>
MB/WW H-ESP	59	Harrisburg WTE	Dauphin	PA	1.54E+08	Tested	Tested	21	23
	<b>H-ESP subtotals</b>					<b>1.54E+08</b>			<b>21</b>
MB/WW UNC	60	Harrisonburg	Harrisonburg	VA	3.14E+07	1.9	2.07	0.1	0.1
	<b>UNC subtotals</b>					<b>3.14E+07</b>			<b>0.1</b>
<b>Totals for all MB/WW</b>					<b>2.05E+10</b>			<b>30</b>	<b>33</b>
MB/REF DSI/H-ESP	61	Davis/Wasatch	Davis	UT	1.25E+08	Tested	Tested	2.7	2.9
	<b>DSI/H-ESP subtotals</b>					<b>1.25E+08</b>			<b>2.7</b>
MB/REF DS/FF	62	Mid Maine Waste Action Corp.	Androscoggin	ME	6.27E+07	0.67	0.72	<0.1	0.1
	<b>DS/FF subtotals</b>					<b>6.27E+07</b>			<b>&lt;0.1</b>
<b>Totals for all MB/REF</b>					<b>1.88E+08</b>			<b>2.7</b>	<b>3.0</b>
MB/RK DS/FF	63	American Ref-Fuel of Delaware Valley	Delaware	PA	1.11E+09	Tested	Tested	0.5	0.5
	<b>DS/FF subtotals</b>					<b>1.11E+09</b>			<b>0.5</b>
MB/RK DS/FF/CI/SNCR	64	York Co.	York	PA	3.97E+08	Tested	Tested	0.1	0.1
	<b>DS/FF/CI/SNCR subtotals</b>					<b>3.97E+08</b>			<b>0.1</b>
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 <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
		<b>DSI/FF subtotals</b>			<b>2.78E+08</b>			<b>&lt;0.1</b>	<b>0.1</b>
MB/RK FF	67	Galax City SW	Grayson	VA	1.76E+07	Tested	Tested	0.2	0.3
		<b>FF subtotals</b>			<b>1.76E+07</b>			<b>0.2</b>	<b>0.3</b>
MB/RK H-ESP	68	Bay Resource Management Center	Bay	FL	1.54E+08	Tested	Tested	8.1	8.9
		<b>H-ESP subtotals</b>			<b>1.54E+08</b>			<b>8.1</b>	<b>8.9</b>
MB/RK C-ESP	69	Sumner Co.	Sumner	TN	6.27E+07	47	93.1	3.0	5.9
		<b>C-ESP subtotals</b>			<b>6.27E+07</b>			<b>3.0</b>	<b>5.9</b>
<b>Totals for all MB/RK</b>					<b>2.02E+09</b>			<b>12</b>	<b>16</b>
MOD/EA DS/FF	70	Wallingford RRF	New Haven	CT	1.32E+08	Tested	Tested	0.1	0.1
		<b>DS/FF subtotals</b>			<b>1.32E+08</b>			<b>0.1</b>	<b>0.1</b>
MOD/EA DSI/FF	71	Springfield RRF	Hampden	MA	1.13E+08	0.025	0.024	<0.1	<0.1
		<b>DSI/FF subtotals</b>			<b>1.13E+08</b>			<b>&lt;0.1</b>	<b>&lt;0.1</b>
MOD/EA WS/C-ESP	72	Pittsfield RRF	Berkshire	MA	1.13E+08	16.2	17	1.8	1.9
		<b>WS/C-ESP subtotals</b>			<b>1.13E+08</b>			<b>1.8</b>	<b>1.9</b>
MOD/EA C-ESP	73	Pope-Douglas Waste	Douglas	MN	2.26E+07	16.2	17	0.4	0.4
	74	Red Wing Solid Waste Boiler Facility	Goodhue	MN	2.26E+07	16.2	17	0.4	0.4
		<b>C-ESP subtotals</b>			<b>4.52E+07</b>			<b>0.8</b>	<b>0.8</b>
MOD/EA H-ESP	75	Pascagoula	Jackson	MS	4.70E+07	118	119	5.6	5.6
		<b>H-ESP subtotals</b>			<b>4.70E+07</b>			<b>5.6</b>	<b>5.6</b>
<b>Totals for all MOD/EA</b>					<b>4.50E+08</b>			<b>8.3</b>	<b>8.4</b>
MOD/SA C-ESP	76	Juneau RRF	Juneau Borough	AK	2.20E+07	16.2	17	0.4	0.4
	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
		<b>C-ESP subtotals</b>			<b>1.14E+08</b>			<b>1.9</b>	<b>1.9</b>
MOD/SA DSI/C-ESP	80	City of Cleburne	Johnson	TX	3.57E+07	16.2	17	0.6	0.6
		<b>DSI/C-ESP subtotals</b>			<b>3.57E+07</b>			<b>0.6</b>	<b>0.6</b>
MOD/SA DSI/H-ESP	81	Harford Co. WTE Fac.	Harford	MD	1.13E+08	Tested	Tested	5.4	6.0
		<b>DSI/H-ESP subtotals</b>			<b>1.13E+08</b>			<b>5.4</b>	<b>6.0</b>
MOD/SA DS/FF/CI	82	Oswego Co. WTE	Oswego	NY	6.27E+07	Tested	Tested	0.1	0.1
		<b>DS/FF/CI subtotals</b>			<b>6.27E+07</b>			<b>0.1</b>	<b>0.1</b>

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

Design <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
MOD/SA DSI/FF	83	Coos Bay Incinerator	Coos	OR	4.70E+07	Tested	Tested	<0.1	<0.1
		<b>DSI/FF subtotals</b>			<b>4.70E+07</b>			<b>&lt;0.1</b>	<b>&lt;0.1</b>
MOD/SA	84	Arlington -Pentagon	Arlington	VA	3.14E+07	16.2	17	0.5	0.5
		<b>MOD/SA subtotals</b>			<b>3.14E+07</b>			<b>0.5</b>	<b>0.5</b>
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
		<b>WS subtotals</b>			<b>5.46E+07</b>			<b>0.9</b>	<b>0.9</b>
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
		<b>UNC subtotals</b>			<b>7.43E+07</b>			<b>1.2</b>	<b>1.3</b>
<b>Totals for all MOD/SA</b>					<b>5.33E+08</b>			<b>10</b>	<b>11</b>
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
		<b>DS/FF/SNCR subtotals</b>			<b>1.57E+09</b>			<b>0.2</b>	<b>0.2</b>
RDF/Ded DS/FF/CI/SNCR	95	Dade Co. RRF	Dade	FL	6.68E+08	Tested	Tested	1.3	1.4
		<b>DS/FF/CI/SNCR subtotals</b>			<b>6.68E+08</b>			<b>1.3</b>	<b>1.4</b>
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
		<b>DS/FF subtotals</b>			<b>1.69E+09</b>			<b>1.1</b>	<b>1.1</b>
RDF/Ded DSI/FF	100	Red Wing Plant	Goodhue	MN	1.82E+08	Tested	Tested	0.1	0.1
		<b>DSI/FF subtotals</b>			<b>1.82E+08</b>			<b>0.1</b>	<b>0.1</b>
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 <sup>a</sup> Class APCD <sup>b</sup>		Facility Name	City Located	State	Activity Level <sup>c</sup> (kg/y)	Emission Factor (ng TEQ/kg)		Annual Air Emissions (g/y)	
						I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>	I-TEQ <sub>DF</sub>	WHO <sub>98</sub> TEQ <sub>DF</sub>
DSI/FF/WSp/SNCR		<b>DSI/FF/WSp/SNCR subtotals</b>			<b>4.44E+07</b>			<b>0.7</b>	<b>0.7</b>
RDF/Ded	102	Central Wayne Co.	Wayne	MI	1.56E+08	Tested	Tested	0.1	0.1
C-ESP		<b>C-ESP subtotals</b>			<b>1.56E+08</b>			<b>0.1</b>	<b>0.1</b>
RDF/Ded	103	Honolulu RRF	Honolulu	HI	5.15E+08	Tested	Tested	2.0	2.2
DS/ESP		<b>DS/ESP subtotals</b>			<b>5.15E+08</b>			<b>2.0</b>	<b>2.2</b>
RDF/Ded	104	SEMASS RRF	Plymouth	MA	7.41E+08	Tested	Tested	0.1	0.10
DS/ESP/FF/CI		<b>DS/ESP/FF/CI subtotals</b>			<b>7.41E+08</b>			<b>0.1</b>	<b>0.10</b>
<b>Totals for all RDF/Ded</b>					<b>5.56E+09</b>			<b>5.6</b>	<b>5.9</b>
FB/RDF	105	Tacoma	Pierce	WA	9.41E+07	0.67	0.72	0.1	0.1
DSI/FF		<b>DSI/FF subtotals</b>			<b>9.41E+07</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals for all FB/RDF</b>					<b>9.41E+07</b>			<b>0.1</b>	<b>0.1</b>
<b>Totals for all MWCs operating in year 2000</b>					<b>2.94E+10</b>			<b>69</b>	<b>77</b>

<sup>a</sup>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.

<sup>b</sup>APCD = air pollution control device. DSI/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).

<sup>c</sup>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**

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

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

2  
3  
4       **4.1. MOTOR VEHICLE FUEL COMBUSTION**

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

17  
18       **4.1.1. Air Literature**

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

21           Gullett and Ryan (2002) characterized CDD/CDF emissions from two heavy duty diesel  
22 trucks under highway driving conditions and while idling: a 1989 Ford with a turbocharged  
23 Cummins engine and mechanical fuel controls and a 1990 Kenworth with a T800 engine  
24 equipped with the first generation of electronic fuel controls. The Ford trailer was loaded at  
25 16,900 kg, and the Kenworth trailer at 8,400 kg. The Kenworth was tested using both a high  
26 mileage and the same engine in rebuilt, or “low mileage” condition. The average emission  
27 factors reported for each vehicle and driving condition are presented below:

- 28  
29       • Ford/highway: 385 pg WHO<sub>98</sub> TEQ/L  
30       • Kenworth/highway (old engine): 58 pg WHO<sub>98</sub> TEQ/L  
31       • Kenworth/highway (rebuilt engine): 24 pg WHO<sub>98</sub> TEQ/L  
32       • Kenworth/idle: 6 pg WHO<sub>98</sub> TEQ/L

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

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

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

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

26 Laroo et al. (2011), Liu et al. (2011) and Hovemann et al. (2010) compared emissions of  
27 dioxins and furans using various catalyzed aftertreatment systems, including diesel oxidation  
28 catalysts, catalyzed diesel particulate filters, and copper and iron zeolite selective catalytic  
29 reduction (SCR) systems that are currently used in on-road diesel trucks in the U.S. These  
30 studies report no increase in dioxin or furan emissions when using catalyzed aftertreatment

1 systems and fuel chlorine levels that were representative and one order of magnitude higher than  
2 what is currently in ultra low sulfur pump diesel fuel.

3 UNEP (2005) presents emission factors for a variety of engine types and fuels. These  
4 were originally presented in units of  $\mu\text{g I-TEQ/MT}$  and are converted to  $\text{pg I-TEQ/L}$  below  
5 (assumes diesel fuel has a density of  $0.85 \text{ kg/L}$  and gasoline has a density of  
6  $0.75 \text{ kg/L}$ —Hazardous Substances Database,  
7 <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB.htm>):

- 8
- 9 • Leaded gasoline, 4-stroke engine— $1,600 \text{ pg I-TEQ/L}$
- 10 • Leaded gasoline, 2-stroke engine— $2,600 \text{ pg I-TEQ/L}$
- 11 • Unleaded gasoline, 4-stroke engine without catalyst— $75 \text{ pg I-TEQ/L}$
- 12 • Unleaded gasoline, 4-stroke engine with catalyst— $0$
- 13 • Unleaded gasoline, 2-stroke engine without catalyst— $1,900 \text{ pg I-TEQ/L}$
- 14 • Diesel engines— $85 \text{ pg I-TEQ/L}$

#### 15

#### 16 **4.1.2. Air Emission Factor**

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

#### 21

#### 22 **4.1.2.1. Leaded Gasoline**

23 The literature indicates that CDD/CDF emissions occur from vehicles using leaded  
24 gasoline, and that considerable variation occurs depending, at least in part, on the types of  
25 additives used in the fuel or motor oil (Ballschmiter et al., 1986; Marklund et al., 1990).

26 The average emission factor, as reported for the tailpipe emission studies performed  
27 using commercial leaded fuel (see Table 4-4 in U.S. EPA, 2006), was  $532 \text{ pg WHO}_{98} \text{ TEQ}_{\text{DF/L}}$   
28 ( $450 \text{ pg I-TEQ}_{\text{DF/L}}$ ), (Marklund et al., 1990; Hagenmaier et al., 1990; Schwind et al., 1991).  
29 This emission factor was applied to 1987 but was not needed for the other years due to the  
30 phaseout of leaded gasoline.

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

#### 4 5 **4.1.2.2. Unleaded Gasoline**

6 The literature documenting results of European studies indicates that CDD/CDF  
7 emissions from vehicles burning unleaded fuels are lower than emissions from vehicles burning  
8 leaded gas with chlorinated scavengers. It also appears, based on the limited data available, that  
9 catalyst-equipped cars have lower emission factors than do noncatalyst-equipped cars (Marklund  
10 et al., 1987; Marklund et al., 1990; Hagenmaier et al., 1990; Schwind et al., 1991). All  
11 automobiles running on unleaded gasoline in the United States are equipped with catalysts  
12 (commonly known as “catalytic converters”). The average emission factor reported for the  
13 tailpipe emission studies performed on catalyst-equipped cars (Hagenmaier et al., 1990; Schwind  
14 et al., 1991; Hutzinger et al., 1992) was calculated as 15.6 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L  
15 (14.9 pg I-TEQ<sub>DF</sub>/L). This emission factor was assumed to apply to each reference year.

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

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

3

#### 4 **4.1.2.3. Diesel Fuel**

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

9 Laroo et al. (2011) reported emission factors for a 2008 model year diesel engine of 1.89  
10 pg I-TEQ/L without aftertreatment under steady-state operation; 1.28 pg I-TEQ/L for an engine  
11 with copper zeolite urea SCR, diesel oxidation catalyst, and catalyzed particulate filter  
12 aftertreatment under transient operation; and 0.21 pg I-TEQ/L for an engine equipped with a  
13 diesel oxidation catalyst and catalyzed particulate filter under transient operation. Liu et al.  
14 (2011) reported emission factors for a 2010 model year diesel engine of 0.31 pg WHO 1998  
15 TEQ/hp-hr without aftertreatment; 0.12 pg WHO 1998 TEQ/hp-hr for an engine with copper  
16 zeolite urea SCR, diesel oxidation catalyst, and catalyzed particulate filter aftertreatment and  
17 0.13 pg WHO 1998 TEQ/hp-hr for an engine equipped with a diesel oxidation catalyst and  
18 catalyzed particulate filter under steady-state operation. Hovemann et al. (2010) reported  
19 emissions factors of 0.11 pg/m<sup>3</sup> for steady-state operation and 0.10 pg/m<sup>3</sup> for transient operation  
20 of a diesel engine with aftertreatment including a diesel oxidation catalyst, copper zeolite SCR  
21 and urea. The Health Effects Institute (2009) reported a range of emissions from 0.13 – 1.4 pg I-  
22 TEQ/L for three diesel engines equipped with catalyzed particulate filters.

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

30 The tunnel study conducted in Baltimore, MD, by Gertler et al. (1996, 1998) shares the  
31 disadvantages of all tunnel studies relative to those that directly measured CDDs and CDFs in

1 tailpipe emissions. Specifically, tunnel studies rely on indirect measurements (rather than  
2 tailpipe measurements), which may introduce bias, and the emission factors calculated from  
3 these studies reflect the mix of vehicles using the tunnel—and not necessarily the overall vehicle  
4 fleet. Also, they reflect the driving conditions of the tunnel (surface slope, speed, braking, etc.),  
5 which may not be representative of usual driving conditions.

6         However, the Gertler et al. (1996, 1998) study does have strengths that are lacking in the  
7 Oehme et al. (1991) tunnel study, and it has advantages over the two U.S. diesel truck tailpipe  
8 studies, including: (a) the study was conducted during the reference year time frame (1995) in  
9 the United States and, thus, reflects U.S. fuels and technology of that time period, (b) virtually no  
10 vehicle using the tunnel was fueled with leaded gasoline, (c) the tunnel walls and streets were  
11 cleaned one week prior to the start of sampling and, in addition, the study analyzed road dust and  
12 determined that resuspended road dust contributed only about 4% of the estimated emission  
13 factors, (d) the heavy-duty vehicles comprised, on average, a relatively large proportion (25.7%)  
14 of vehicles using the tunnel, and (e) a large number of heavy-duty vehicles—approximately  
15 33,000—passed through the tunnel during the sampling period, which generates confidence that  
16 the emission factor is representative of interstate trucks. It should be noted, though, that the  
17 study was most representative of heavy duty trucks because these were the primary type of  
18 vehicle using the tunnel. For other diesel vehicles (e.g., light duty trucks, automobiles, buses),  
19 the study is less representative, and uncertainty is greater.

20         Considering the strengths and weaknesses of the available emission factor data from the  
21 tailpipe and tunnel studies, the mean TEQ emission factor reported by Gertler et al. (1996,  
22 1998)—182 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/km (172 pg I-TEQ<sub>DF</sub>/km)—is assumed to represent the best  
23 current estimate of the average emission factor for on-road diesel-fueled vehicles. This emission  
24 factor was converted to a per-liter basis assuming a fuel efficiency of 2.98 km/L (U.S. EPA,  
25 2003a). This yields an emission factor of 540 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (510 pg I-TEQ<sub>DF</sub>/L), which  
26 was assumed to apply to all reference years for both on-road and off-road vehicles. It is likely  
27 that the fleet average emission factor has decreased over the reference years (due to  
28 improvements in engine/emission designs), but insufficient information was available to account  
29 for this. For application to off-road vehicles, the factor is considered preliminary because it is  
30 based on truck testing, and it is uncertain how well it applies to other types of diesel vehicles

1 such as heavy duty vehicles used in construction, tractors, off-road military vehicles, ships, and  
2 locomotives.

3

#### 4 **4.1.3. Air Activity Level**

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

7

##### 8 **4.1.3.1. Gasoline**

9 EIA (2008a) provides data on the total “motor gasoline product supplied,” which  
10 represents all gasoline consumed in the United States. These data were reported as barrels per  
11 year and are converted here to liters by multiplying by 42 gal/barrel and 3.78 L/gal. For 1987, it  
12 is assumed that 24% of the gasoline was leaded ( $1.00 \times 10^{11}$  L) and the remainder unleaded  
13 ( $3.18 \times 10^{11}$  L) (EIA, 1993). For years 1995 and 2000, it is assumed that leaded gasoline was  
14 produced in negligible amounts. The total amount of unleaded gasoline consumed in 1995 was  
15  $4.00 \times 10^{11}$  L, and the total amount consumed in 2000 was  $4.93 \times 10^{11}$  L. EIA does not provide  
16 data that allow the gasoline uses to be divided between on road and off road. However,  
17 U.S. EPA (2006) provided estimates for the year 2000 suggesting that 5% of the gasoline was  
18 used for off-road engines (kilometers driven on road were converted to liters, assuming an  
19 average fuel efficiency of 10 km/L). This percentage was assumed to apply to all reference  
20 years, resulting in the following estimates:

21

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

1     **4.1.3.2. Diesel**

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

- 6
- 7     • Diesel fuel used on road is 55% of the total.
  - 8     • Diesel fuel used off road (includes off-highway, farm, railroad, vessels, and military  
9 categories) is 20% of the total.
  - 10    • Other uses of distillate fuels (includes residential, commercial, industrial, and electric  
11 power categories) make up 25% of the total.
- 12

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

- 15
- 16    • 1987— $9.48 \times 10^{10}$  L on road,  $3.45 \times 10^{10}$  L off road
  - 17    • 1995— $1.02 \times 10^{11}$  L on road,  $3.71 \times 10^{10}$  L off road
  - 18    • 2000— $1.19 \times 10^{11}$  L on road,  $4.32 \times 10^{10}$  L off road
- 19

20     **4.1.4. Air Releases**

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

24

25     **4.1.5. Water Releases—None**

26

27     **4.1.6. Solid Residue Releases**

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

30

31     **4.1.7. Products—None**

32

1 **4.1.8. Release Summary**

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

3

<b>Inventory Decision Criteria for Motor Vehicle Combustion—On-road</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

4

5

<b>Inventory Decision Criteria for Motor Vehicle Combustion—Off-road</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

6

## Motor Vehicle Combustion

### Air Releases

#### Emission Factors

##### *Leaded Gasoline*

- 1987—530 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (450 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).

##### *Unleaded Gasoline*

- 1987—16 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (15 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).
- 1995—16 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (15 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).
- 2000—16 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (15 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).

##### *Diesel*

- 1987—540 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (510 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).
- 1995—540 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (510 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).
- 2000—540 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (510 pg I-TEQ<sub>DF</sub>/L) (Preliminary for off-road).

#### Activity Levels

##### *Leaded Gasoline, On-road*

- 1987— $9.5 \times 10^{10}$  L/yr.

##### *Leaded Gasoline, Off-road*

- 1987— $0.5 \times 10^{10}$  L/yr.

##### *Unleaded Gasoline, On-road*

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

##### *Unleaded Gasoline, Off-road*

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

##### *Diesel, On-road*

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

##### *Diesel, Off-road*

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

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<b>Motor Vehicle Combustion (continued)</b>	
<b>Releases</b>	
<i>Leaded Gasoline, On--road</i>	
<ul style="list-style-type: none"> <li>• 1987—50 g WHO<sub>98</sub> TEQ<sub>DF</sub> (43 g I-TEQ<sub>DF</sub>)</li> </ul>	
<i>Leaded Gasoline, Off--road</i>	
<ul style="list-style-type: none"> <li>• 1987—3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>) (Preliminary).</li> </ul>	
<i>Unleaded Gasoline, On-road</i>	
<ul style="list-style-type: none"> <li>• 1987—5 g WHO<sub>98</sub> TEQ<sub>DF</sub> (5 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (6 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (7 g I-TEQ<sub>DF</sub>).</li> </ul>	
<i>Unleaded Gasoline, Off-road</i>	
<ul style="list-style-type: none"> <li>• 1987—0.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.2 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 1995—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.3 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 2000—0.4 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.4 g I-TEQ<sub>DF</sub>) (Preliminary).</li> </ul>	
<i>Diesel, On-road</i>	
<ul style="list-style-type: none"> <li>• 1987—51 g WHO<sub>98</sub> TEQ<sub>DF</sub> (48 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—55 g WHO<sub>98</sub> TEQ<sub>DF</sub> (52 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—64 g WHO<sub>98</sub> TEQ<sub>DF</sub> (61 g I-TEQ<sub>DF</sub>).</li> </ul>	
<i>Diesel, Off-road</i>	
<ul style="list-style-type: none"> <li>• 1987—19 g WHO<sub>98</sub> TEQ<sub>DF</sub> (18 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 1995—20 g WHO<sub>98</sub> TEQ<sub>DF</sub> (19 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 2000—23 g WHO<sub>98</sub> TEQ<sub>DF</sub> (22 g I-TEQ<sub>DF</sub>) (Preliminary).</li> </ul>	
<b>Water Releases</b>	
No information was found suggesting that water releases from internal combustion engines would contain CDDs and CDFs.	
<b>Solid Residue Releases</b>	
No information was found suggesting that solid residue releases from internal combustion engines would contain CDDs and CDFs.	
<b>Products</b>	
None.	

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## **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.

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

16

#### 17       **4.2.1.1. Air Releases from Indoor Residential Wood Burners**

18           A study conducted in Australia by Gras et al. (2002) measured dioxin emissions from a  
19 variety of wood-burning appliances and wood types. The average values for various wood types  
20 were 7.5 ng WHO<sub>98</sub> TEQ/kg for eucalyptus, 19 ng WHO<sub>98</sub> TEQ/kg for manufactured wood, and  
21 <1 ng WHO<sub>98</sub> TEQ/kg for softwoods.

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

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

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

4 UNEP (2005) recommended an emission factor of 100 µg I-TEQ/TJ (TJ = terajoule or  
5  $10^{12}$  joule) for virgin biomass-fired stoves. Assuming that wood combustion produces  
6 12–15 MJ/kg where MJ = megajoule or  $10^6$  joule (UNEP, 2005), this converts to 1.2 to  
7 1.5 ng I-TEQ/kg of wood burned.

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

13 Activity estimates were derived from EIA (2008b), which reports energy production from  
14 residential wood burning in BTUs. These were converted to mass of wood burned by dividing  
15 these values by 14,080 BTU/kg (average heat value of seasoned wood at 20% moisture—ORNL,  
16 2008). This yields estimates of 71 MMT in 1987, 37 MMT in 1995 and 30 MMT in 2000.

#### 17 18 **4.2.1.2. Air Releases from Residential Outdoor Wood-Fired Boilers**

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

27 Because OWBs operate in a cyclic fashion, they can produce large amounts of smoke.  
28 When an OWB is in the “off” cycle and does not need to generate heat, the air damper closes to  
29 cut off the air supply. This creates an oxygen-starved environment in which the fire smolders,  
30 creating smoke and creosote that condenses on the internal steel surfaces. When heat needs to be  
31 produced, the air damper opens and natural draft forces air into the firebox, pushing the smoke

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1 and air pollutants out the stack. Measured emissions peak when the unit has received a fresh  
2 load of fuel and the wood has not yet reached a charcoal stage. In the field test conducted by  
3 NESCAUM, the unit's internal stack temperature never reached levels that would have resulted  
4 in complete combustion. In comparing emissions of particulate matter (PM) from various  
5 sources, it was noted that one OWB can emit as much PM as four heavy duty diesel trucks.  
6 Generally, OWBs do not use catalytic or noncatalytic emission control devices commonly  
7 employed by other residential combustion devices (NESCAUM, 2006).

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

14 EPA estimates that there were more than 100,000 OWBs in use in the United States in  
15 2007; NESCAUM estimates that more than 155,000 units have been sold since 1990 (U.S. EPA,  
16 2007a). An average household in the Northeast (where many of these units are used) consumes  
17 63.1 million BTU per year for space heating (EIA, 2001). Multiplying this value by the  
18 100,000 OWBs in use suggests they produced a total of 6.3 trillion BTU in 2007. Dividing this  
19 value by 14,080 BTU per kilogram (the average heat value of seasoned wood at 20% moisture  
20 [ORNL, 2008]) yields a total wood consumption of 448,000 MTs in 2007, and this is assumed to  
21 apply to 2000. Because it is not known how many units were in operation in 1987 and 1995, the  
22 activity level could not be estimated for these years.

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

#### 28 29 **4.2.1.3. Water Releases—None**

1       **4.2.1.4. Solid Residues from All Residential Wood Burning**

2           EPA (2006) summarizes studies measuring CDDs/CDFs in chimney soot from wood-  
3 burning stoves and fireplaces by several researchers (Bumb et al., 1980; Nestruck and Lamparski,  
4 1982, 1983; Clement et al., 1985; Bacher et al., 1992; Van Oostam and Ward, 1995; Dumler-  
5 Gradl et al., 1995). The CDD/CDF levels ranged from 80 to 350 ng WHO<sub>98</sub> TEQ/kg.

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

13  
14       **4.2.1.5. Solid Residue Emission Factor**

15           The CDD/CDF levels in soot are likely to be higher than bottom ash from wood burning,  
16 so the soot based studies noted above were not used to select an emission factor. Instead, the  
17 UNEP (2005) recommendation of 10 ng I-TEQ/kg of ash residue (based on Wunderli et al.,  
18 [1996] data for wood-burning bottom ash) was selected as the best for residential wood burning.  
19 The congener profile for bottom ash from natural wood burning reported by Wunderli et al.  
20 (1996) indicated that the WHO<sub>98</sub> TEQs were only about 4% greater than the I-TEQs. On this  
21 basis, the UNEP recommendation can also be expressed as 10 ng WHO<sub>98</sub> TEQ/kg of ash residue.

22  
23       **4.2.1.6. Solid Residue Activity Level**

24           The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to  
25 8% ash (Ragland et. al, 1991). A mid-range value of 3% is assumed here for all wood burned.  
26 Multiplying this percentage by the amount of wood consumed (as reported above) yields the ash  
27 production amounts for each reference year: 2.13 MMT in 1987, 1.11 MMT in 1995, and  
28 0.9 MMT in 2000.

1     **4.2.1.7. Solid Residue Releases**

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

11  
12     **4.2.1.8. Release Summary**

13             The inventory decision criteria and release estimates to all media are summarized below:  
14

<b>Inventory Decision Criteria for Indoor Residential Wood Burners</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

15

<b>Residential Wood Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factor</b>	
<p><b><i>Indoor Residential Wood Burners</i></b></p> <ul style="list-style-type: none"> <li>• 1987—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 1995—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 2000—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of wood.</li> </ul> <p><b><i>Outdoor Wood-Fired Boilers</i></b></p> <ul style="list-style-type: none"> <li>• 1987—20 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of wood (Preliminary).</li> <li>• 1995—20 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of wood (Preliminary).</li> <li>• 2000—20 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of wood (Preliminary).</li> </ul>	
<b>Activity Level</b>	
<p><b><i>Indoor Residential Wood Burners</i></b></p> <ul style="list-style-type: none"> <li>• 1987—71 MMT.</li> <li>• 1995—37 MMT.</li> <li>• 2000—30 MMT.</li> </ul> <p><b><i>Outdoor Wood-Fired Boilers</i></b></p> <ul style="list-style-type: none"> <li>• 1987—Not Available.</li> <li>• 1995—Not Available.</li> <li>• 2000—0.448 MMT (Preliminary).</li> </ul>	
<b>Releases</b>	
<p><b><i>Indoor Residential Wood Burners</i></b></p> <ul style="list-style-type: none"> <li>• 1987—36 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—19 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—15 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> </ul> <p><b><i>Outdoor Wood-Fired Boilers</i></b></p> <ul style="list-style-type: none"> <li>• 1987—Not Available</li> <li>• 1995—Not Available</li> <li>• 2000—9 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>	
<b>Water Releases</b>	
None.	

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<b>Residential Wood Combustion (continued)</b>	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 1995—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 2000—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (I-TEQ<sub>DF</sub>/kg) of ash.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—2.13 MMT of ash.</li> <li>• 1995—1.11 MMT of ash.</li> <li>• 2000—0.9 MMT of ash.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—21 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—11 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—9 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Products</b>	
None.	

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## **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<sub>98</sub> 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<sub>98</sub> TEQ<sub>DF</sub>/kg wood (0.56 ng I-TEQ<sub>DF</sub>/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

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1 overall average of the five tested facilities in Canada (Luthe et al., 1998) and the United States  
2 (U.S. EPA, 1987), 13.2 ng I-TEQ<sub>DF</sub>/kg of wood, was applied to all three reference years. Based  
3 on the congener profile reported by Luthe et al. (1998), this converts to 15.3 ng WHO<sub>98</sub> TEQ/kg.

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

#### 7 8 **4.2.2.2. Water Literature—None**

#### 9 10 **4.2.2.3. Solid Residue Releases**

11 As indicated in U.S. EPA (2006), the ash concentrations from the NCASI Handbook  
12 (13.2 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg) appears to fall within the range of values reported in the various  
13 studies and a reasonable value for mixed bottom and fly ash. Oeheme and Muller (1995)  
14 measured CDD/CDF levels in ash from wood-fired boilers in Switzerland. The levels in bottom  
15 ash were on the order of 1 ng I-TEQ/kg when natural wood was incinerated. However, in filter  
16 ash the levels were about two orders of magnitude higher. Burning of waste wood from house  
17 demolition and construction resulted in concentrations in the range of 1–10 ng I-TEQ/kg.

18 The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to  
19 8% ash (Ragland et al, 1991). A mid-range value of 3% is assumed here for all wood burned.  
20 Multiplying this percentage by the amount of wood consumed (as reported in the release  
21 summary below) yields the ash production amounts for each reference year: 3.48 MMT in 1987,  
22 3.51 MMT in 1995, and 3.48 MMT in 2000.

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

- 27
- 28 • 1987—46 g WHO<sub>98</sub> TEQ<sub>DF</sub>/kg
  - 29 • 1995—46 g WHO<sub>98</sub> TEQ<sub>DF</sub>/kg
  - 30 • 2000—46 g WHO<sub>98</sub> TEQ<sub>DF</sub>/kg

1 **4.2.2.4. Release Summary**

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

3  
4

<b>Inventory Decision Criteria for Industrial Wood Combustion</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Industrial Wood Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factor</b>	
<i>Nonsalt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—0.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.56 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 1995—0.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.56 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 2000—0.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.56 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> </ul>	
<i>Salt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—15 ng WHO<sub>98</sub> TEQ/kg (13 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 1995—15 ng WHO<sub>98</sub> TEQ/kg (13 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> <li>• 2000—15 ng WHO<sub>98</sub> TEQ/kg (13 ng I-TEQ<sub>DF</sub>/kg) of wood.</li> </ul>	
<b>Activity Level</b>	
<i>Nonsalt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—116 MMT.</li> <li>• 1995—117 MMT.</li> <li>• 2000—116 MMT.</li> </ul>	
<i>Salt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—0.5 MMT.</li> <li>• 1995—0.5 MMT.</li> <li>• 2000—0.8 MMT.</li> </ul>	
<b>Releases</b>	
<i>Nonsalt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—70 g WHO<sub>98</sub> TEQ<sub>DF</sub> (65 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—70 g WHO<sub>98</sub> TEQ<sub>DF</sub> (65 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—70 g WHO<sub>98</sub> TEQ<sub>DF</sub> (65 g I-TEQ<sub>DF</sub>).</li> </ul>	
<i>Salt-Laden Wood</i>	
<ul style="list-style-type: none"> <li>• 1987—8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (7 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (7 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—12 g WHO<sub>98</sub> TEQ<sub>DF</sub> (10 g I-TEQ<sub>DF</sub>).</li> </ul>	
<i>Total Industrial Releases</i>	
<ul style="list-style-type: none"> <li>• 1987—78 g WHO<sub>98</sub> TEQ<sub>DF</sub> (72 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—78 g WHO<sub>98</sub> TEQ<sub>DF</sub> (72 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—82 g WHO<sub>98</sub> TEQ<sub>DF</sub> (75 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
All ash is assumed to be landfilled and, therefore, is not considered to be an environmental release.	

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<b>Industrial Wood Combustion (continued)</b>
<b>Products</b>
None.

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3 **4.3. OIL COMBUSTION**

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

13 Fuel Grades 5 and 6 are residual oils and sometimes referred to as “heavy fuel oils.”  
14 Number 6 fuel oil is sometimes referred to as Bunker C. Fuel Grade 4 is either distillate oil or a  
15 mixture of distillate and residual oils. Distillate oils are more volatile and less viscous than  
16 residual oils, which have negligible nitrogen and ash content, and usually contain less than  
17 0.3% sulfur (by weight). Distillate oils are used mainly in domestic and small commercial  
18 applications. The heavier residual oils (Grades 5 and 6), being more viscous and less volatile  
19 than distillate oils, must be heated for ease of handling and to facilitate proper atomization.  
20 Because residual oils are produced from the residue after the lighter fractions are removed from  
21 the crude oil, they may contain significant quantities of ash, nitrogen, and sulfur.

22

23 **4.3.1. Institutional/Commercial and Residential Oil Combustion**

24 **4.3.1.1. Air Releases**

25 No changes were made to the emission factors. No testing for CDD/CDF emissions from  
26 commercial or residential oil-fired combustion units in the United States could be located.  
27 However, EPA (1997a) estimated CDD/CDF congener group and TEQ emission factors using  
28 average CDD/CDF concentrations reported for soot samples from 21 distillate fuel oil-fired  
29 furnaces used for central heating in Canada and a PM emission factor for distillate fuel oil  
30 combustors (300 mg/L oil) obtained from AP-42 (U.S. EPA, 1995a). The TEQ emission factor

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1 estimate—0.19 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/L of oil (0.15 ng I-TEQ<sub>DF</sub>/L of oil)—was derived using the  
2 calculated emission factors for 2,3,7,8-TCDD, 2,3,7,8-TCDF, and the 10 congener groups.  
3 These results are near the upper end of the range from Pfeiffer et al. (2000) who measured  
4 CDD/CDF emissions from oil fired household appliances used in Germany. Emission factors  
5 were in the range of 0.025 to 0.135 ng I-TEQ/kg.

6 Minor updates were made to the activity estimates. EIA (2008a) data were used to derive  
7 the activity levels. EIA supplied yearly data on total distillate fuel oil and total residual fuel oil  
8 supplied in the United States. EIA also provided a breakdown of fuel oil sales by sector for the  
9 years back to 2001. The sector percentages for 2001 were assumed to apply to each of the  
10 reference years. These percentages were multiplied by the totals (also used conversion factors of  
11 42 gal/barrel and 3.79 L/gal) to estimate the amount of distillate fuel oil consumed in the  
12 residential and commercial sectors. On this basis, the following estimates were made for each  
13 reference year: 1987—29.4 billion L, 1995—31.7 billion L, and 2000—36.9 billion L.

14  
15 **4.3.1.2. *Water Releases—None***

16  
17 **4.3.1.3. *Solid Residue Releases—None***

18  
19 **4.3.1.4. *Products—None***

20  
21 **4.3.1.5. *Release Summary***

22 The inventory decision criteria and release estimates are summarized below:  
23

<b>Inventory Decision Criteria for Institutional/Commercial and Residential Oil Combustion</b>	
	<b>Air Water Solids Products</b>
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

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<b>Institutional/Commercial and Residential Oil Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—190 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (150 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> <li>• 1995—190 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (150 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> <li>• 2000—190 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (150 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—29.4 billion L.</li> <li>• 1995—31.7 billion L.</li> <li>• 2000—36.9 billion L.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (4 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (5 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (6 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
These facilities do not have wastewater releases.	
<b>Solid Residue Releases</b>	
These facilities do not have solid releases.	
<b>Products</b>	
None.	

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#### 4.3.2. Utility Sector and Industrial Oil Combustion

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

1     **4.3.2.1. Air Literature**

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

7             Some boilers use low-NO<sub>x</sub> burners, which reduce flame turbulence, delay fuel/air  
8 mixing, and establish fuel-rich zones within the boiler during initial combustion. The longer,  
9 less intense flames that result from the altered combustion lower flame temperatures and reduce  
10 thermal NO<sub>x</sub> formation (Colburn, 1996). Because low-NO<sub>x</sub> burners reduce temperatures and,  
11 thus, the completeness of combustion the potential exists for increased CDD/CDF formation.  
12 However, this has not yet been evaluated via stack testing.

13  
14     **4.3.2.2. Air Emission Factor**

15             EPA (2006) based the emission factor on the average of the EPRI (1994) and EPA  
16 (1997a) studies. The emission factor—230 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L oil combusted  
17 (200 pg I-TEQ<sub>DF</sub>/L oil combusted)—was applied to all three reference years.

18  
19     **4.3.2.3. Activity Level**

20             Updated EIA data were used to derive the activity levels. EIA supplied yearly data on  
21 total distillate fuel oil and total residual fuel oil supplied in the United States. EIA also provided  
22 a breakdown of fuel oil sales by sector for the years back to 2001. The sector percentages for  
23 2001 were assumed to apply to each of the reference years. Multiplying these percentages by the  
24 totals yields the following estimates for each reference year (also used conversion factors of  
25 42 gal/barrel and 3.79 L/gal):

26  
27 Distillate Fuel Oil—Industrial and Electric Power Use

- 28  
29     • 1987—10.4 billion L  
30     • 1995—11.2 billion L  
31     • 2000—13.0 billion L

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1 Residual Fuel Oil—Total

2

- 3 • 1987—73.4 billion L
- 4 • 1995—49.5 billion L
- 5 • 2000—53.0 billion L

6

7 **4.3.2.4. Air Releases**

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

9

10 **4.3.2.5. Water Releases—None**

11

12 **4.3.2.6. Solid Residue Releases—None**

13

14 **4.3.2.7. Products—None**

15

16 **4.3.2.8. Release Summary**

17 The inventory decision criteria and release estimates are summarized below:

18

<b>Inventory Decision Criteria for Utility Sector and Industrial Oil Combustion</b>	
	<b>Air Water Solids Products</b>
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

19

20

21

<b>Utility Sector and Industrial Oil Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—230 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (200 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> <li>• 1995—230 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (200 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> <li>• 2000—230 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (200 pg I-TEQ<sub>DF</sub>/L) of oil combusted.</li> </ul>	
<b>Activity Level</b>	
<ul style="list-style-type: none"> <li>• 1987—83.8 billion L.</li> <li>• 1995—60.7 billion L.</li> <li>• 2000—66.0 billion L.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—19 g WHO<sub>98</sub> TEQ<sub>DF</sub> (17 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—14 g WHO<sub>98</sub> TEQ<sub>DF</sub> (12 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—15 g WHO<sub>98</sub> TEQ<sub>DF</sub> (13 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
These facilities do not have wastewater releases.	
<b>Solid Residue Releases</b>	
These facilities do not have solid releases.	
<b>Products</b>	
These facilities do not have products.	

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### 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

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1 Steel Mills - 0.080  
2 Cement Kilns - 0.033  
3 Others - 0.095 (includes: marine boilers, pulp & paper mills, commercial boilers)  
4  
5 Total - 0.780  
6

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

#### 9 10 **4.3.3.1. Air Literature**

11  
12 Bremmer et al. (1994) measured the CDD/CDF emissions from the combustion of used  
13 oil by small combustion units in the Netherlands. Flue gases from a garage stove consisting of  
14 an atomizer fueled by spent lubricating oil from diesel engines (35 mg Cl<sup>1</sup>/kg) were reported to  
15 contain 0.1 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> (2 ng I-TEQ<sub>DF</sub>/kg) oil burned. The flue gases from a hot water  
16 boiler consisting of a rotary cup burner fueled with the organic phase of rinse water from oil  
17 tanks (340 mg Cl<sup>1</sup>/kg) contained 0.2 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> (4.8 ng I-TEQ<sub>DF</sub>/kg) oil burned. The flue  
18 gases from a steam boiler consisting of a rotary cup burner fueled by processed spent oil (240 mg  
19 Cl<sup>1</sup>/kg) contained 0.3 ng I-TEQ<sub>DF</sub>/Nm<sup>3</sup> (6 ng I-TEQ<sub>DF</sub>/kg) oil burned. The emission factor for a  
20 ferry burning heavy fuel oil containing 11 ng/kg organic chlorine was 3.2 to 6.5 ng I-TEQ<sub>DF</sub>/kg  
21 oil burned. From these data, Bremmer et al. (1994) derived an average emission factor for  
22 combustion of used oil of 4 ng I-TEQ<sub>DF</sub>/kg oil burned.

23 Measured data from the burning of recycled waste oils are available from Austria, where  
24 emissions from a small incinerator gave a concentration of 0.02 ng TEQ/Nm<sup>3</sup> (at 11% O<sub>2</sub>)  
25 equivalent to an emission factor of 0.37 ng TEQ/kg of waste oil burned (LUA, 1997).

#### 26 27 28 **4.3.3.2. Air Emission Factor**

29  
30 The emission factor measured by Bremmer et al. (1994) for small combustion units was  
31 selected as most relevant to space heaters, i.e. 2 ng I-TEQ<sub>DF</sub>/kg. Based on the limited data from  
32 only one study and uncertainty about how the units tested by Bremmer et al. compare to space  
33 heaters in the U.S., this is considered to be a preliminary estimate.

34  
35  
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1     **4.3.3.3. Activity Level**

2  
3           The total amount of waste oil burned in 1983 was 0.59 billion gallons (USEPA, 1993).  
4 Comparing this estimate with the 2006 estimate (described above) and assuming linear growth,  
5 implies that used oil combustion has increased at a rate of about 1.4% per year. The 2006 data  
6 indicates that 14.5 % of the total waste burned was in space heaters. Assuming this percentage  
7 remains constant and using the annual growth rate, allows estimates of the amount of oil burned  
8 in space heaters for each of the reference years (converted to kg based on 3.78 L/gal and density  
9 of 0.88 kg/L):

- 10  
11 1987 – 0.30 billion kg  
12 1995 – 0.33 billion kg  
13 2000 – 0.35 billion kg  
14

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

17  
18  
19     **4.3.3.4. Air Releases**

20  
21           The air releases were estimated by multiplying the emission factor and activity estimates.  
22

23     **4.3.3.5. Water Releases – None**

24  
25     **4.3.3.6. Solid Residue Releases – None.**

26  
27     **4.3.3.7. Products – None.**

28  
29     **4.3.3.8. Release Summary**

30  
31 The inventory decision criteria and release estimates are summarized below:  
32  
33

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

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<b>Inventory Decision Criteria for Waste Oil Combustion</b>	
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

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<b>Waste Oil Combustion</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987 – 2 ng I-TEQ<sub>DF</sub>/kg oil combusted (Preliminary)</li> <li>• 1995 – 2 ng I-TEQ<sub>DF</sub>/kg oil combusted (Preliminary)</li> <li>• 2000 – 2 ng I-TEQ<sub>DF</sub>/kg oil combusted (Preliminary)</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987 – 0.30 billion kg (Preliminary)</li> <li>• 1995 – 0.33 billion kg (Preliminary)</li> <li>• 2000 – 0.35 billion kg (Preliminary)</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987 – 0.60 g I-TEQ<sub>DF</sub> (Preliminary)</li> <li>• 1995 – 0.66 g I-TEQ<sub>DF</sub> (Preliminary)</li> <li>• 2000 – 0.70 g I-TEQ<sub>DF</sub> (Preliminary)</li> </ul>
<b>Water Releases</b>
These facilities do not have wastewater releases.
<b>Solid Residue Releases</b>
These facilities do not have solid releases.
<b>Products</b>
These facilities do not have products.

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#### **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.

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1     **4.4.1.1. Air Releases**

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

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

21           In the year 2000, 10 facilities with an SIC code for electric services reported dioxin  
22 releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these  
23 facilities was 63.2 g, which EPA estimates is equal to 8.9 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other  
24 media were reported. Also, in the year 2000, two facilities with an SIC code for electric and  
25 other services combined reported dioxin releases under EPA’s TRI program (U.S. EPA, 2008).  
26 The sum of the air releases across these facilities was 457 g, which EPA estimates is equal to  
27 22.2 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were reported. As explained in Chapter 1, the  
28 TRI data are not used to make quantitative estimates in this document but rather as supportive  
29 evidence that releases do occur.

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

1     **4.4.1.2. Water Releases**

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

6  
7     **4.4.1.3. Solid Residue Releases**

8           Dyke et al. (1997) provided data on residues from industrial coal combustion in the  
9 United Kingdom: Concentrations in fly ash were 0.23–8.7 ng TEQ/kg ash, and grate ash were  
10 0.02–13.5 ng TEQ/kg. UNEP (2005) used these data to derive an average value of  
11 4 ng I-TEQ/kg. A limited amount of CDD/CDF concentration data have been developed for ash  
12 from coal combustion facilities in the United States (U.S. EPA, 1999c), and these data are for  
13 wastes that are comanaged (i.e., combinations of fly ash, bottom ash, boiler slag, and flue gas  
14 desulfurization wastes). A total of 15 samples were taken from 11 disposal sites. The total mean  
15 concentration was 0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg).

16           The total mean concentration from EPA (1999c) was selected as the only U.S. data  
17 available and within the range reported for the United Kingdom. This value of  
18 0.73 ng WHO<sub>9</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg) was assumed to apply to all reference years.

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

- 22
- 23     • 1987—75.4 MMT
  - 24     • 1995—83.6 MMT
  - 25     • 2000—98.2 MMT

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

- 1 • 1987—22.6 MMT
- 2 • 1995—25.1 MMT
- 3 • 2000—29.5 MMT

4

5 The potential for environmental releases from these uses is unknown, but it is assumed here that  
6 all of the CDD/CDF in the recycled ash represent an environmental release (release estimates are  
7 shown in the summary below). The emission factor presented above is based on recent testing at  
8 11 disposal sites, but it is uncertain how much actual release occurs from these products.

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

12

- 13 • 1987—38.5 g WHO<sub>98</sub> TEQ<sub>DF</sub> (32.7 g I-TEQ<sub>DF</sub>)
- 14 • 1995—42.7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (36.3 g I-TEQ<sub>DF</sub>)
- 15 • 2000—50.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (42.6 g I-TEQ<sub>DF</sub>)

16

17 **4.4.1.4. *Product Literature—None***

18

19 **4.4.1.5. *Release Summary***

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

21

22

<b>Inventory Decision Criteria for Industrial Coal-Fired Utilities</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

1

<b>Industrial Coal-Fired Utilities</b>	
<b>Air Releases</b>	
<b>Emission Factor</b>	<ul style="list-style-type: none"> <li>• 1987—0.078 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.079 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—0.078 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.079 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—0.078 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.079 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—651 MMT.</li> <li>• 1995—771 MMT.</li> <li>• 2000—894 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—51 g WHO<sub>98</sub> TEQ<sub>DF</sub> (51 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—60 g WHO<sub>98</sub> TEQ<sub>DF</sub> (61 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—70 g WHO<sub>98</sub> TEQ<sub>DF</sub> (71 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>	
Because some evidence exists that wastewater from these facilities may contain CDDs and CDFs, they are classified as possible but unquantifiable (Not quantifiable) sources.	
<b>Solid Residue Releases</b>	
<b>Emission Factor</b>	<ul style="list-style-type: none"> <li>• 1987—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 1995—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.079 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 2000—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.079 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—22.6 MMT ash.</li> <li>• 1995—25.1 MMT ash.</li> <li>• 2000—29.5 MMT ash.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—17 g WHO<sub>98</sub> TEQ<sub>DF</sub> (14 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—18 g WHO<sub>98</sub> TEQ<sub>DF</sub> (16 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—22 g WHO<sub>98</sub> TEQ<sub>DF</sub> (18 g I-TEQ<sub>DF</sub>).</li> </ul>

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#### 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.

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1     **4.4.2.2. Water Literature**

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

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7     **4.4.2.3. Solid Residue Releases**

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

14  
15     **4.4.2.4. Release Summary**

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

17

<b>Inventory Decision Criteria for Industrial Coal-Fired Boilers</b>	
	<b>Air   Water   Solids   Products</b>
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

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<b>Industrial Coal-Fired Boilers</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.6 ng I-TEQ<sub>DF</sub>/kg) of coal combusted.</li> <li>• 1995—0.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.6 ng I-TEQ<sub>DF</sub>/kg) of coal combusted.</li> <li>• 2000—0.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.6 ng I-TEQ<sub>DF</sub>/kg) of coal combusted.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—68.2 MMT.</li> <li>• 1995—66.3 MMT.</li> <li>• 2000—59.2 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—48 g WHO<sub>98</sub> TEQ<sub>DF</sub> (41 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—46 g WHO<sub>98</sub> TEQ<sub>DF</sub> (40 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—41 g WHO<sub>98</sub> TEQ<sub>DF</sub> (36 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
Because some evidence exists that wastewater from these facilities may contain CDDs and CDFs, they are classified as possible but unquantifiable sources.	
<b>Solid Residue Releases</b>	
These releases are included in the estimates for coal-fired utilities presented in Section 4.4.1.	
<b>Products</b>	
No information was found suggesting that products from these facilities would contain CDDs and CDFs.	

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#### 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  $\mu\text{g}/\text{ton}$  of coal burned. Testing with an insulated chimney yielded an emission factor of 126 I-TEQ  $\mu\text{g}/\text{ton}$  of coal burned. A pronounced effect of the temperature profile in the chimney on PCDD/F emissions was identified, suggesting formation in the chimney.

14

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<sub>DF</sub>/kg for anthracite coal and 5.7 to 9.3 ng I-TEQ<sub>DF</sub>/kg [midpoint,

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1 7.5 ng I-TEQ<sub>DF</sub>/kg] for bituminous coal). Wevers et al. (2003) measured CDD/CDF emissions  
2 from various types of household appliances used in Belgium. The average emission factor for  
3 anthracite coal burners was 77.1 ng I-TEQ/kg. UNEP (2005) reports that European studies  
4 generally show a range of 1.6 to 50 ng TEQ/kg for typical coal and emission factors as high as  
5 660 ng I-TEQ/kg for high chlorine coals. Ultimately UNEP (2005) recommends 3 ng I-TEQ/kg  
6 for domestic burning with typical coals. Based on the similarity of the emission factor data  
7 summarized by UNEP for typical coals and estimates by Eduljee and Dyke (1996), the emission  
8 factor was upgraded from preliminary to quantitative. The congener data for emissions from  
9 normal lignite (Thub et al., 1995), indicate that the WHO<sub>98</sub> TEQs were less than 9% higher than  
10 the I-TEQs. Based on this small difference, the I-TEQ emission factor was assumed to be  
11 essentially equivalent when expressed as WHO<sub>98</sub> TEQs.

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

#### 18 **4.4.3.2. Water Releases—None**

#### 20 **4.4.3.3. Solid Residue Releases**

21 The solid residues from coal-fired utility boilers are likely to be similar to the solid  
22 residues from residential units. On this basis, the same emission factor is assumed to apply, i.e.,  
23 0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg). UNEP (2005) suggests a “first estimate”  
24 emission factor for residues from coal fired stoves of 5,000 ng I-TEQ/kg. This is based on  
25 measurements in soot, which may not be representative of bottom ash. A preliminary confidence  
26 rating is assigned to this emission factor because it is based on testing from different facilities.

27 The total amount of ash generated by these facilities is assumed to be 10% of the total  
28 coal used. On this basis, the solid residues are estimated to be 0.16 MMT in 1987, 0.08 MMT in  
29 1995, and 0.05 MMT in 2000. Some of this ash is likely to be disposed along with household  
30 trash and taken to a municipal landfill. This portion would not be considered an environmental  
31 release. Others may dispose of it on their property in a manner that is open to the environment.

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**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:

<b>Inventory Decision Criteria for Residential Coal Combustion</b>			
	<b>Air</b>	<b>Water</b>	<b>Solids Products</b>
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

<b>Residential Coal Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<i>Anthracite</i>	
<ul style="list-style-type: none"> <li>• 1987—2.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (2.1 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—2.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (2.1 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—2.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (2.1 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Bituminous</i>	
<ul style="list-style-type: none"> <li>• 1987—7.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (7.5 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—7.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (7.5 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—7.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (7.5 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels<sup>a</sup></b>	
<ul style="list-style-type: none"> <li>• 1987—1.6 MMT.</li> <li>• 1995—0.8 MMT.</li> <li>• 2000—0.5 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—10 g WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>.</li> <li>• 1995—5 g WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>.</li> <li>• 2000—3 g WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>.</li> </ul>	
<b>Water Releases</b>	
These facilities do not have wastewater releases.	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> <li>• 1995—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> <li>• 2000—0.73 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.62 ng I-TEQ<sub>DF</sub>/kg) (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.16 MMT.</li> <li>• 1995—0.08 MMT.</li> <li>• 2000—0.05 MMT.</li> </ul>	
<b>Releases<sup>b</sup></b>	
<ul style="list-style-type: none"> <li>• 1987—0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.1 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 1995—0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.1 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 2000— &lt;0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (&lt;0.1 g I-TEQ<sub>D</sub>) (Preliminary).</li> </ul>	
<b>Products</b>	
These facilities do not have products.	

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<sup>a</sup>Note: 72.5% of the coal burned is bituminous, and 27.5% is anthracite.

<sup>b</sup>Note: An unknown portion of this is landfilled and, therefore, is not considered a release to the open environment.

1                                   **5. COMBUSTION SOURCES OF CDDs/CDFs: OTHER**  
2                                   **HIGH-TEMPERATURE SOURCES**  
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5   **5.1. CEMENT KILNS**

6   **5.1.1. Air Releases**

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

9           The present report uses higher emission factors for cement kilns burning hazardous waste  
10 in 1987 and 1995 than kilns not burning hazardous waste (emission factors were not needed in  
11 2000 for hazardous waste burners because virtually all facilities had been tested). As discussed  
12 below, these higher emissions were more likely due to APCD temperatures than the hazardous  
13 waste.

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

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

31  
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- 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<sub>98</sub> TEQ<sub>DF</sub>. 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.

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1 **5.1.3. Solid Residue Releases**

2 No changes were made to the solid residue release estimates from cement kilns.

3 However, additional background information is provided below.

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

15 A wide range of CDD/PCDF concentrations in the CKD has been measured. A range  
16 from 0.001 to 30 ng TEQ/kg has been reported for U.K. kilns (Dyke et al., 1997), and  
17 1–40 ng TEQ/kg were summarized for German tests (SCEP, 1994). As discussed in EPA  
18 (2006), for kilns burning hazardous waste, the CKD concentration is assumed to be  
19 35 ng I-TEQ/kg (n = 5), and for the kilns not burning hazardous waste, the CKD concentration is  
20 assumed to be 0.003 ng I-TEQ/kg (n = 6). These emission factors were applied to all reference  
21 years. They are considered preliminary because of the inconsistency in measured values and  
22 lack of understanding for the differences. The dioxin concentrations in CKD were also used to  
23 estimate the amounts of CDD/CDFs in landfilled CKD, as shown below:

24

	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

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1 **5.1.4. Products**

2 Clinker is the primary product of cement kilns and is ultimately used to make Portland  
3 cement. EPA (1993a) described the results of sampling and analysis of clinker conducted in  
4 1992 and 1993. Clinker samples were collected from five cement kilns burning nonhazardous  
5 waste and six kilns burning hazardous waste. CDDs/CDFs were not detected in any of the  
6 samples. Some of the CKD is beneficially reused as discussed above. Releases associated with  
7 beneficial uses of CKD are covered under the solid residue section.

8

9 **5.1.5. Release Summary**

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

11

<b>Inventory Decision Criteria for Cement Kilns</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Cement Kilns Not Burning Hazardous Waste</b>	
<b>Air Releases</b>	
<b>Emission Factor</b>	<ul style="list-style-type: none"> <li>• 1987—0.27 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.26 ng I-TEQ/kg) of clinker produced.</li> <li>• 1995—0.27 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.26 ng I-TEQ/kg) of clinker produced.</li> <li>• 2000—0.27 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.26 ng I-TEQ/kg) of clinker produced.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—47.2 billion kg of clinker.</li> <li>• 1995—61.3 billion kg of clinker.</li> <li>• 2000—63.7 billion kg of clinker.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—13 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (12 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 1995—17 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (16 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 2000—17 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (17 g I-TEQ<sub>DF</sub>/yr).</li> </ul>
<b>Water Releases</b>	
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.	
<b>Solid Residue Releases</b>	
<b>Emission Factor</b>	<ul style="list-style-type: none"> <li>• 1987—0.003 ng I-TEQ/kg (Preliminary).</li> <li>• 1995—0.003 ng I-TEQ/kg (Preliminary).</li> <li>• 2000—0.003 ng I-TEQ/kg (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—632 million kg.</li> <li>• 1995—547 million kg.</li> <li>• 2000—480 million kg.</li> </ul>
<b>Releases for Beneficial Uses</b>	<ul style="list-style-type: none"> <li>• 1987—&lt;0.1 g I-TEQ (Preliminary).</li> <li>• 1995—&lt;0.1 g I-TEQ (Preliminary).</li> <li>• 2000—&lt;0.1 g I-TEQ (Preliminary).</li> </ul>
<b>Products</b>	
No information was found suggesting that clinker contained measureable levels of CDDs and CDFs. Beneficial uses of CKD are covered under solid residues.	

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<b>Cement Kilns Burning Hazardous Waste</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—APCD &gt; 232°C: 31 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (29 ng I-TEQ/kg) of clinker produced. APCD &lt; 232°C: 1.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.0 ng I-TEQ/kg) of clinker produced.</li> <li>• 1995—APCD &gt; 232°C: 31 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (29 ng I-TEQ/kg) of clinker produced. APCD &lt; 232°C: 1.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.0 ng I-TEQ/kg) of clinker produced.</li> <li>• 2000—EFs not needed because all individual facilities were tested.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—APCD &gt; 232°C: 3.8 billion kg of clinker. APCD &lt; 232°C: 1 billion kg of clinker.</li> <li>• 1995—APCD &gt; 232°C: 5.04 billion kg of clinker. APCD &lt; 232°C: 1.26 billion kg of clinker.</li> <li>• 2000—Activity estimates not needed because all individual facilities were tested.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—APCD &gt; 232°C: 120 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (110 g I-TEQ<sub>DF</sub>/yr). APCD &lt; 232°C: 1 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (1 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 1995—APCD &gt; 232°C: 160 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (150 g I-TEQ<sub>DF</sub>/yr). APCD &lt; 232°C: 1 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (1 g I-TEQ<sub>DF</sub>/yr).</li> <li>• 2000—19 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr (17 g I-TEQ<sub>DF</sub>/yr).</li> </ul>	
<b>Water Releases</b>	
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.	
<b>Solid Residue Releases</b>	
<b>Emission Factor</b>	
<ul style="list-style-type: none"> <li>• 1987—35 ng I-TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 1995—35 ng I-TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 2000—35 ng I-TEQ<sub>DF</sub>/kg (Preliminary).</li> </ul>	
<b>Activity Level for Beneficial Uses</b>	
<ul style="list-style-type: none"> <li>• 1987—120 million kg.</li> <li>• 1995—104 million kg.</li> <li>• 2000—94 million kg.</li> </ul>	

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<b>Cement Kilns Burning Hazardous Waste (continued)</b>
<b>Releases for Beneficial Uses</b> <ul style="list-style-type: none"> <li>• 1987—4 g I-TEQ (Preliminary).</li> <li>• 1995—4 g I-TEQ (Preliminary).</li> <li>• 2000—3 g I-TEQ (Preliminary).</li> </ul>
<b>Products</b>
No information was found suggesting that clinker contained measurable levels of CDDs and CDFs. Beneficial uses of CKD are covered under solid residues.

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**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<sub>DF</sub> to air in 1990 (Federal Register, 1998) and 2.4 g I-TEQ<sub>DF</sub> 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<sub>98</sub> TEQ<sub>DF</sub>/kg (2.06 ng I-TEQ<sub>DF</sub>/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:

<b>Inventory Decision Criteria for Lightweight Aggregate Kilns</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Lightweight Aggregate Kilns</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—not needed.</li> <li>• 1995—not needed.</li> <li>• 2000—2.0 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (2.1 ng I-TEQ<sub>DF</sub>/kg) of waste feed.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—not needed.</li> <li>• 1995—not needed.</li> <li>• 2000—903,000 MT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—3 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—2 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
No information was found suggesting that water releases from these facilities would contain CDDs and CDFs.	
<b>Solid Residue Releases</b>	
No information was found suggesting that solid residues from these facilities would contain CDDs and CDFs.	
<b>Products</b>	
No information was found suggesting that products from these facilities would contain CDDs and CDFs.	

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1 **5.3. ASPHALT MIXING PLANTS**

2 **5.3.1. Air Releases**

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

5 The original report estimated the emission factor on the basis of tests at two U.S.  
6 facilities. The original report also included information on testing at one facility in the  
7 Netherlands: 0.047 ng I-TEQ/kg (Bremmer et al., 1994) and three facilities in Germany: 0.0002,  
8 0.0035, and 0.0038 ng I-TEQ/kg (Umweltbundesamt, 1996). Because the European facilities are  
9 likely similar to those in the United States, they were averaged in with the U.S. facilities to  
10 derive an emission factor of 0.0095 ng I-TEQ/kg, and this was applied to all reference years.  
11 This factor falls within the range recommended by UNEP (2005) for asphalt mixing plants:  
12 0.0007 to 0.07 ng I-TEQ/kg. The confidence rating was upgraded from preliminary to  
13 quantifiable based on the additional testing used to support it and similarity to UNEP, 2005.

14 The original report provided an activity estimate of 500 million tons for 2000 based on  
15 1996 survey data. Because this industry is fairly stable in terms of growth and the activity data  
16 are near the midpoint of the reference year range, it is reasonable to assume it applies to all  
17 reference years. Asphalt can be produced at both fixed and mobile facilities. It is unclear if this  
18 activity estimate includes both types of plants or only those at fixed locations. The National  
19 Cooperative Highway Research Program Web site and other related sites were searched, but no  
20 relevant information was found.

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22 **5.3.2. Water Releases**

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

25  
26 **5.3.3. Solid Residue Releases**

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

1 **5.3.4. Products**

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

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5 **5.3.5. Release Summary**

6 The inventory decision criteria and releases are summarized below:  
7

<b>Inventory Decision Criteria for Asphalt Mixing Plants</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Asphalt Mixing Plants</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—0.009 ng I-TEQ/kg of asphalt produced.</li> <li>• 1995—0.009 ng I-TEQ/kg of asphalt produced.</li> <li>• 2000—0.009 ng I-TEQ/kg of asphalt produced.</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—500 MMT.</li> <li>• 1995—500 MMT.</li> <li>• 2000—500 MMT.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—5 g I-TEQ.</li> <li>• 1995—5 g I-TEQ.</li> <li>• 2000—5 g I-TEQ.</li> </ul>
<b>Water Releases</b>
No information was found suggesting that water releases from these facilities would contain CDDs and CDFs.
<b>Solid Residue Releases</b>
Any solid residues from these facilities would be landfilled and not considered an environmental release.
<b>Products</b>
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

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## **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<sub>98</sub> TEQ<sub>DF</sub>/barrel (1.52 ng I-TEQ<sub>DF</sub>/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<sub>98</sub> TEQ<sub>DF</sub>. 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.

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1 **5.4.2. Water Releases**

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

6  
7 **5.4.3. Solid Residue Releases**

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

12  
13 **5.4.4. Product Literature**

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

16  
17 **5.4.5. Release Summary**

18 The inventory decision criteria and releases are summarized below:

<b>Inventory Decision Criteria for Petroleum-Refining Catalyst Regeneration Plants</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Petroleum-Refining Catalyst Regeneration Plants</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—1.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/barrel (1.5 ng I-TEQ<sub>DF</sub>/barrel) of reformer feed.</li> <li>• 1995—1.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/barrel (1.5 ng I-TEQ<sub>DF</sub>/barrel) of reformer feed.</li> <li>• 2000—1.6 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/barrel (1.5 ng I-TEQ<sub>DF</sub>/barrel) of reformer feed.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—1,390 million barrels.</li> <li>• 1995—1,410 million barrels.</li> <li>• 2000—1,380 million barrels.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>	
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.	
<b>Solid Residue Releases</b>	
Any solid residues from these facilities would be landfilled and not considered an environmental release.	
<b>Products</b>	
No information was found suggesting that products from these facilities would contain CDDs and CDFs.	

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**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**

1 **5.5.3. Solid Residue Releases**

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

4  
5 **5.5.4. Products—None**

6  
7 **5.5.5. Release Summary**

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

11

<b>Inventory Decision Criteria for Cigarette Smoking</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Cigarette Smoking</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—1.7 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/cigarette (1.6 pg I-TEQ<sub>DF</sub>/cigarette).</li> <li>• 1995—1.7 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/cigarette (1.6 pg I-TEQ<sub>DF</sub>/cigarette).</li> <li>• 2000—1.7 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/cigarette (1.6 pg I-TEQ<sub>DF</sub>/cigarette).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—575 billion cigarettes.</li> <li>• 1995—487 billion cigarettes.</li> <li>• 2000—440 billion cigarettes.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.9 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—0.8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.8 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.7 g I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
No information was found suggesting that ash from cigarette smoking would contain CDDs and CDFs.
<b>Products</b>
Not applicable.

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**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).

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

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 6 **5.7.2. Water Releases—None**

7  
 8 **5.7.3. Solid Residue Releases—None**

9  
 10 **5.7.4. Products**

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

13  
 14 **5.7.5. Release Summary**

15 The inventory decision criteria and releases are summarized below:

16

<b>Inventory Decision Criteria for Carbon Reactivation Furnaces</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Carbon Reactivation Furnaces</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—1.2 ng (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) per kg of reactivated carbon.</li> <li>• 1995—1.2 ng (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) per kg of reactivated carbon.</li> <li>• 2000—1.2 ng (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) per kg of reactivated carbon.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—48,000 MT.</li> <li>• 1995—65,000 MT.</li> <li>• 2000—65,000 MT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—0.1 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—0.1 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.1 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> </ul>
<b>Water Releases</b>	
No water releases are produced.	
<b>Solid Residue Releases</b>	
No solid residues are produced.	
<b>Products</b>	
No information was found suggesting that products from these facilities would contain CDDs and CDFs.	

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**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**

1 **5.8.3. Solid Residue Releases**

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

6  
7 **5.8.4. Products**

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

10  
11 **5.8.5. Release Summary**

12 The inventory decision criteria and releases are summarized below:

<b>Inventory Decision Criteria for Kraft Black Liquor Recovery Boilers</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Kraft Black Liquor Recovery Boilers</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.03 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.03 ng I-TEQ<sub>DF</sub>/kg) of black liquor solids.</li> <li>• 1995—0.03 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.03 ng I-TEQ<sub>DF</sub>/kg) of black liquor solids.</li> <li>• 2000—0.010 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of black liquor solids.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—69.8 MMT.</li> <li>• 1995—80.8 MMT.</li> <li>• 2000—90.7 MMT for Kraft recovery furnaces.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—2 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—2 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.9 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr.</li> </ul>
<b>Water Releases</b>	
No water releases are produced.	
<b>Solid Residue Releases</b>	
Any solid residues from these facilities would be landfilled and not considered an environmental release.	
<b>Products</b>	
No information was found suggesting that products from these facilities would contain CDDs and CDFs.	

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## **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).

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1 **5.9.2. Regulations**

2 None specific to dioxins.

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4 **5.9.3. Air Releases**

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

10 UNEP (2005) reports that data from Europe on seven kilns, of which four were rotary  
11 kilns and three were shaft kilns, showed CDD/PCDF concentrations below 0.1 ng TEQ/Nm<sup>3</sup>.  
12 Measurements at two annular shaft kilns in Germany were all below 0.05 ng I-TEQ/Nm<sup>3</sup>.

13 High concentrations of CDD/PCDF have been measured at three kilns, two rotary kilns,  
14 and one shaft kiln, in Sweden. The measurements made between 1989 and 1993 gave  
15 concentrations between 4.1 and 42 ng N-TEQ/Nm<sup>3</sup>. All measurements of high CDD/PCDF  
16 concentrations have been explained by the raw material, fuel content, or less-than-optimum  
17 burning conditions, underlining the importance of controlling the kiln inputs and maintaining a  
18 stable kiln operation (IPPC, 2001).

19 UNEP (2005) recommends two emission factors. For no dust controls or poor fuel,  
20 10 µg I-TEQ/MT of CaO are recommended, and for kilns with good dust controls,  
21 0.07 µg I-TEQ/MT of CaO are recommended.

22 In the year 2000, one facility with an SIC code for lime reported dioxin releases under the  
23 EPA TRI program (U.S. EPA, 2008). The total air releases for this facility was 0.73 g, which  
24 EPA estimates is equal to 0.15 g WHO<sub>98</sub> TEQ<sub>DF</sub>. The total land releases for this facility was  
25 2.8 g, which EPA estimates is equal to 0.6 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were  
26 reported. As explained in Chapter 1, the TRI data are not used to make quantitative estimates in  
27 this document but rather as supportive evidence that releases do occur.

28 For 2000, the emission factor of 0.0058 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of CaO was used on the  
29 basis of “NCASI Handbook of Chemical Specific Information for SARA Section 313 Form R  
30 Reporting.” The factors provided in this handbook were compiled from test data supplied to  
31 NCASI by a variety of sources, including NCASI member companies who had performed the

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1 tests in response to a regulatory program. Congener-specific CDD/CDF TEQ emission factors  
2 were provided (see Table 5-1).

3 For 2000, NCASI provided estimates of activity levels for Kraft lime kilns (Gillespie,  
4 2002). The activity levels were reported to be 13 MMT. Insufficient information was available  
5 to make release estimates for the other reference years.

6

#### 7 **5.9.4. Water Releases**

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

10

#### 11 **5.9.5. Solid Residue Releases**

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

14

#### 15 **5.9.6. Products**

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

18

#### 19 **5.9.7. Release Summary**

20 The inventory decision criteria and releases are summarized below:

21

<b>Inventory Decision Criteria for Lime Kilns</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Lime Kilns</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—NA.</li> <li>• 1995—NA.</li> <li>• 2000—0.006 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of CaO.</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—NA.</li> <li>• 1995—NA.</li> <li>• 2000—13 MMT.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—NA.</li> <li>• 1995—NA.</li> <li>• 2000—0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub>/yr.</li> </ul>
<b>Water Releases</b>
No information was found suggesting that any water releases from these facilities would contain CDDs and CDFs.
<b>Solid Residue Releases</b>
Any solid residues from these facilities would be landfilled and are not considered an environmental release.
<b>Products</b>
No information was found suggesting that products from these facilities would contain CDDs and CDFs.

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## **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:

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<b>Inventory Decision Criteria for Glass Manufacturing</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Glass Manufacturing</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.02 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> <li>• 1995—0.02 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> <li>• 2000—0.02 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—18 MMT.</li> <li>• 1995—18 MMT.</li> <li>• 2000—18 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—0.4 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—0.4 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—0.4 g I-TEQ<sub>DF</sub>.</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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1 **5.11. OTHER IDENTIFIED SOURCES**

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

10

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

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

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

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CaO = Calcium oxide.

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1     **6. COMBUSTION SOURCES OF CDDs/CDFs MINIMALLY CONTROLLED AND**  
2                                   **UNCONTROLLED COMBUSTION SOURCES**  
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5     **6.1. COMBUSTION OF LANDFILL GAS**

6     **6.1.1. Air Releases**

7             No changes were made to the air-release estimates. The emission factor was derived by  
8 averaging test results for one landfill flare in California (CARB, 1990) and one in the  
9 Netherlands (Bremmer et al., 1994). This value was assumed to apply to all reference years:  
10 1.4 ng I-TEQ<sub>DF</sub>/m<sup>3</sup>. The emission factors for the two facilities differed by a factor of six. UNEP  
11 (2005) used studies from Germany and the U.K. to derive an emission factor of 8 µg I-TEQ/TJ of  
12 gas burned. Assuming that the landfill gas has a heating value of 16 MJ/m<sup>3</sup> (half that of natural  
13 gas), this converts to 0.13 ng I-TEQ/m<sup>3</sup>. Based on the limited data and inconsistency in emission  
14 factors this was considered preliminary. As described in the 2006 document, survey data and  
15 assumptions were used to derive activity estimates.  
16

17     **6.1.2. Water Releases**

18             No wet scrubbers are used for these facilities, so no releases to surface waters should  
19 occur.  
20

21     **6.1.3. Solid Residue Releases—None**  
22

23     **6.1.4. Products—None**  
24

25     **6.1.5. Release Summary**

26             The inventory decision criteria and releases to all media are summarized below:  
27

<b>Inventory Decision Criteria for Landfill Gas</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Combustion of Landfill Gas</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—1.4 ng I-TEQ<sub>DF</sub>/m<sup>3</sup> (Preliminary).</li> <li>• 1995—1.4 ng I-TEQ<sub>DF</sub>/m<sup>3</sup> (Preliminary).</li> <li>• 2000—1.4 ng I-TEQ<sub>DF</sub>/m<sup>3</sup> (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—1.35 billion m<sup>3</sup>.</li> <li>• 1995—4.7 billion m<sup>3</sup>.</li> <li>• 2000—16 billion m<sup>3</sup>.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—2 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—7 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—22 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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1 **6.2. ACCIDENTAL FIRES**

2 **6.2.1. Structural Fires**

3 **6.2.1.1. Air Releases**

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

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

18 The presence of manufactured boards and treated lumber in structures is expected to  
19 increase dioxin emissions relative to the combustion of untreated natural wood. As discussed in  
20 Section 4.2, Tame et al. (2007) reviewed the literature on the role of preservatives in the  
21 formation of dioxin in the combustion of wood. They conclude that current and emerging wood  
22 preservatives significantly increase dioxin formation during combustion in domestic stoves and  
23 in fires. Also Bhargava et al. (2002) conducted calorimeter testing and derived emission factors  
24 of 20.5 ng WHO<sub>98</sub> TEQ/kg for chip boards and 15.4 ng WHO<sub>98</sub> TEQ/kg for medium density  
25 fiberboard (MDF) compared to nondetect to 2.5 ng WHO<sub>98</sub> TEQ/kg for natural woods.

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

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1 No changes were made to the activity estimates which were derived from survey data in FEMA  
2 (1997, 2001) and are presented in the release summary below.

#### 3 4 **6.2.1.2. Water Releases**

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

#### 8 9 **6.2.1.3. Solid Residue Releases**

10 Solid residue releases are possible because CDDs and CDFs have been measured in solid  
11 residues remaining after structural fires. EPA (2006) summarized six field studies with residue  
12 concentrations ranging from 0.03 to 130  $\mu\text{g I-TEQ}_{\text{DF}}/\text{kg}$ . This wide data range is understandable  
13 considering that the amount/types of treated wood and household products found in structures is  
14 likely to be highly variable. The geometric mean of 2  $\mu\text{g I-TEQ}_{\text{DF}}/\text{kg}$  of residue was selected as  
15 a central value. This was converted to an emission factor by assuming that 15% of the fuel is  
16 converted to ash (this is based on the assumption that structural fires will generate ash at a  
17 similar rate as observed for bottom ash in municipal waste combustion, which is reported by  
18 UNEP [2005] to be typically 10–20%). This yields an emission factor of 300 ng I-TEQ<sub>DF</sub>/kg of  
19 material burned, which was assumed to apply to all reference years. Based on an analysis of the  
20 congener data reported by Christmann et al. (1989b) for soot from a building fire, this emission  
21 factor will be the same when converted to WHO<sub>98</sub> TEQs. This value is similar to the UNEP,  
22 2005 recommendation of 400 ng I-TEQ<sub>DF</sub>/kg of material burned.

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

#### 26 27 **6.2.1.4. Products—None**

#### 28 29 **6.2.1.5. Release Summary**

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

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

4

<b>Inventory Decision Criteria for Structural Fires</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Structural Fires</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—32 µg I-TEQ<sub>DF</sub>/fire (Preliminary).</li> <li>• 1995—32 µg I-TEQ<sub>DF</sub>/fire (Preliminary).</li> <li>• 2000—32 µg I-TEQ<sub>DF</sub>/fire (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—746,000 fires.</li> <li>• 1995—574,000 fires.</li> <li>• 2000—512,000 fires.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—24 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—18 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—16 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Water Releases</b>
Possible but unquantifiable releases.
<b>Solid Residue Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—300 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of material burned.</li> <li>• 1995—300 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of material burned.</li> <li>• 2000—300 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of material burned.</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—860,000 tons.</li> <li>• 1995—660,000 tons.</li> <li>• 2000—589,000 tons.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—260 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—200 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—180 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> </ul>
<b>Products</b>
None.

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## 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

1 car, and one railway car). This study suggests an emission factor of 0.044 mg I-TEQ<sub>DF</sub> for cars  
2 and trucks and 2.6 mg I-TEQ<sub>DF</sub>/fire for other vehicles. These values were assumed for all  
3 reference years. They are uncertain because Wichmann et al. (1993, 1995) based their estimates  
4 on surface deposits. This procedure may not have fully accounted for volatile CDDs/CDFs,  
5 which were reported by Merk et al. (1995) to account for the majority of CDDs/CDFs formed  
6 during a fire. Given the indirect method of measuring emissions, they are considered  
7 preliminary estimates. UNEP (2005) derived an emission factor of 0.094 mg I-TEQ<sub>DF</sub>/incident.  
8 This was also based on Wichmann et al. (1995) and represents an average across all vehicle  
9 types.

10 The activity estimates were based on the number of vehicle fires reported in the United  
11 States: approximately 561,530 in 1987 (FEMA, 1997), 406,000 in 1995 (U.S. DOC, 1997), and  
12 341,600 in 2000 (FEMA, 2001). Also, the assumption was made that 99% of those fires  
13 involved cars and trucks (the approximate percentage of all U.S. motor vehicles that are  
14 in-service cars and trucks; U.S. DOC, 1995).

15

#### 16 **6.2.2.2. Water Releases**

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

21

#### 22 **6.2.2.3. Solid Residue Releases**

23 The original document (US EPA, 2006) did not address solid residue releases. Solid  
24 residue releases are possible because CDDs and CDFs have been measured in solid residues  
25 remaining after vehicle fires. Wichmann et al. (1995) measured an average of  
26 0.01 mg I-TEQ<sub>DF</sub>/fire for cars and trucks and 0.8 mg I-TEQ<sub>DF</sub>/fire for other vehicles. These  
27 values were adopted here for all reference years using the same data; UNEP (2005) derived a  
28 solid residues emission factor of 0.018 mg I-TEQ<sub>DF</sub>/incident for all vehicles. These emission  
29 factors were combined with the same activity data reported above to estimate releases.

30

1 **6.2.2.4. Products—None**

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3 **6.2.2.5. Release Summary**

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

5

<b>Inventory Decision Criteria for Vehicle Fires</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Vehicle Fires</b>
<b>Air Releases</b>
<p><b>Emission Factors</b></p> <p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—0.044 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> <li>• 1995—0.044 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> <li>• 2000—0.044 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—2.6 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> <li>• 1995—2.6 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> <li>• 2000—2.6 mg I-TEQ<sub>DF</sub>/incident (Preliminary).</li> </ul>
<p><b>Activity Levels</b></p> <p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—556,000 vehicle fires.</li> <li>• 1995—402,000 vehicle fires.</li> <li>• 2000—338,000 vehicle fires.</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—5,600 vehicle fires.</li> <li>• 1995—4,060 vehicle fires.</li> <li>• 2000—3,400 vehicle fires.</li> </ul>
<p><b>Releases</b></p> <p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—24 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—18 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—15 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—15 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—11 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—9 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul> <p><i>All Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—39 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—29 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—24 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>

<b>Vehicle Fires (continued)</b>
<b>Water Releases</b>
Possible but unquantifiable releases.
<b>Solid Residue Releases</b>
<b>Emission Factors</b>
<p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—0.01 mg I-TEQ<sub>DF</sub>/incident.</li> <li>• 1995—0.01 mg I-TEQ<sub>DF</sub>/incident.</li> <li>• 2000—0.01 mg I-TEQ<sub>DF</sub>/incident.</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—0.8 mg I-TEQ<sub>DF</sub>/incident.</li> <li>• 1995—0.8 mg I-TEQ<sub>DF</sub>/incident.</li> <li>• 2000—0.8 mg I-TEQ<sub>DF</sub>/incident.</li> </ul>
<b>Activity Levels</b>
<p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—556,000 vehicle fires.</li> <li>• 1995—402,000 vehicle fires.</li> <li>• 2000—338,000 vehicle fires.</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—5,600 vehicle fires.</li> <li>• 1995—4,060 vehicle fires.</li> <li>• 2000—3,400 vehicle fires.</li> </ul>
<b>Releases</b>
<p><i>Cars and Trucks</i></p> <ul style="list-style-type: none"> <li>• 1987—6 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—4 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—3 g I-TEQ<sub>DF</sub>.</li> </ul> <p><i>Other Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—5 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—3 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—3 g I-TEQ<sub>DF</sub>.</li> </ul> <p><i>All Vehicles</i></p> <ul style="list-style-type: none"> <li>• 1987—11 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—7 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—6 g I-TEQ<sub>DF</sub>.</li> </ul>

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## 1 **6.3. LANDFILL FIRES**

### 2 **6.3.1. Air Releases**

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

10 Collet and Fiani (2006) reported on the measurement of PAH, PCB, and CDD/CDF  
11 emission from simulated forest and landfill fires. For the landfill simulations, samples were  
12 collected from two landfills located in southwest France. They collected samples from what they  
13 characterized as the superficial part of the landfill ground, only the first 15 cm. These samples  
14 included municipal wastes and nonhazardous industrial wastes containing various plastics, wood,  
15 rubber, rags, and so on. The combustion chamber had an air flow of 1,800 nm<sup>3</sup>/hour,  
16 corresponding to 22.5 volume changes per hour, to simulate open burning conditions. Emissions  
17 were sampled near the chamber exit and prior to the scrubber. They conducted two landfill fire  
18 simulations, and the emission factors for CDD/CDFs, in ng I-TEQ/kg, were 242 and  
19 233 ng I-TEQ/kg. Collet and Fiani also provided emission factors for 12 dioxin-like PCBs, in  
20 ng I-TEQ/kg, and they were 9.9 and 16.6 ng I-TEQ/kg. Their landfill samples were collected  
21 over a surface area of 2 m<sup>2</sup>, allowing generation of emission factors on an area basis. The  
22 emission factors for CDD/CDFs, in ng I-TEQ/m<sup>2</sup>, were 1380 and 1321, and for the  
23 12 dioxin-like PCBs, also in ng I-TEQ/m<sup>2</sup>, were 56.3 and 94.2.

24 Persson and Bergstrom (1991) conducted experiments simulating surface and deep fires  
25 and estimated an emission factor of 1000 ng Nordic TEQ/kg of material burned for landfill fires.  
26 This value (assumed equal to 1000 ng I-TEQ/kg) was also adopted by UNEP (2005). This factor  
27 is about four times higher than the factor developed by Collet and Fiani (2006). The midpoint of  
28 this range, or 600 ng I-TEQ/kg, was adopted here for each reference year. Neither Persson and  
29 Bergstrom (1991) nor Collet and Fiani (2006) reported individual congener data that would have  
30 allowed converting this I-TEQ estimate to a WHO<sub>98</sub> TEQ estimate. However, Ruokojarvi et al.  
31 (1995) reported congener profiles for air concentrations measured during a landfill fire in

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1 Finland. This profile suggest that the WHO<sub>98</sub> TEQs would be about 20% greater than the  
2 I-TEQs. On this basis, the emission factor of 600 ng I-TEQ/kg was converted to  
3 700 ng WHO<sub>98</sub> TEQ/kg. The kinds of wastes and combustion conditions occurring in landfill  
4 fires are likely to be highly variable. It is very uncertain how well these are represented in the  
5 limited experiments used to derive the emission factors. Therefore, this emission factor was  
6 assigned a preliminary confidence rating.

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

11 In order to use the per kg emission factors reported above, it is necessary to estimate the  
12 amount of waste burned in landfill fires. Persson and Bergstrom (1991) assumed that 100,000 kg  
13 of material are burned in each surface fire and 350,000 kg are burned in deep fires. The  
14 midpoint of this range (225,000 kg) was multiplied by the number of landfill fires occurring in  
15 the United States. The U.S. Fire Administration (USFA, 2001) reports that an average of  
16 8,300 landfill fires occur each year (where landfills are defined broadly to include public or  
17 private areas where waste is buried; this includes municipal solid waste landfills and general  
18 refuse disposal areas and dumps in open ground). This suggests that a total of 1.9 MMT of  
19 material/year are burned in landfill fires in the United States. No information was found on how  
20 the number of landfill fires has changed over the reference years, and this amount (1.9 MMT)  
21 was assumed to apply to each of the years. As discussed above, the actual trend is probably  
22 downward because improved regulations and increases in methane recovery systems at landfills  
23 are likely to have reduced landfill fire frequency/magnitude over this time frame. Considering  
24 the lack of data to accurately reflect this trend and the uncertainty in the assumptions about the  
25 amount of waste burned per fire, these activity estimates are considered preliminary  
26 (Preliminary).

27 As shown below, this approach suggests a total release of 1,100 g I-TEQ. Another way  
28 to estimate landfill fire releases is by using a per fire emission factor. Personn and Bergstrom  
29 (1991) estimated that 35 g Nordic TEQ were released from landfills fires in Sweden. This  
30 estimate assumed that 217 fires occurred per year (167 surface fires and 50 deep fires). This  
31 implies an average release of 0.16 g Nordic TEQ/fire. Multiplying this by the number of fires

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1 occurring in the United States (8,300/year as reported by the USFA, 2001) suggests a total  
 2 release of 1,300 g Nordic TEQ. This value is similar to the original one using a per capita  
 3 approach, which gave estimates of about 1,000 g I-TEQ/year (assuming minor differences  
 4 between Nordic TEQs and I-TEQs). Although these alternative approaches suggest similar  
 5 releases, the release estimate is still considered preliminary due to the uncertainties in both the  
 6 emission factor and activity estimates.

7  
 8 **6.3.2. Water Releases—None**

9  
 10 **6.3.3. Solid Residue Releases—None**

11  
 12 **6.3.4. Products—None**

13  
 14 **6.3.5. Release Summary**

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

16

<b>Inventory Decision Criteria for Landfill Fires</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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1

<b>Landfill Fires</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—700 ng WHO<sub>98</sub> TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary).</li> <li>• 1995—700 ng WHO<sub>98</sub> TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary).</li> <li>• 2000—700 ng WHO<sub>98</sub> TEQ/kg (600 ng I-TEQ/kg) of material burned (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—1.9 MMT (Preliminary).</li> <li>• 1995—1.9 MMT (Preliminary).</li> <li>• 2000—1.9 MMT (Preliminary).</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—1,300 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1,100 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 1995—1,300 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1,100 g I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 2000—1,300 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1,100 g I-TEQ<sub>DF</sub>) (Preliminary).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
None.
<b>Products</b>
None.

2

3 **6.4. FOREST AND BRUSH FIRES**

4 **6.4.1. Air Releases**

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

7 Ikeguchi and Tanaka (1999) simulated the open burning of several waste types using a  
8 large furnace with open doors. The flue gas was sampled immediately downstream of the  
9 furnace. One test was conducted with tree and leaf materials. A total of 162.7 kg of this material  
10 were burned in a batch mode lasting 33 minutes. The emission factor was estimated as  
11 4.7 I-TEQ/kg of waste. UNEP (2005) used this study to support their recommended emission  
12 factor of 5 ng TEQ/kg of biomass burned for forest fires.

13 Gonczi et al. (2005) measured dioxin emissions from burning various types of domestic  
14 wastes under a variety of conditions. One test involved the open burning of garden waste, which  
15 was composed of approximately one half wood branches and one half leaves and grass. A

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1 sampling hood was mounted 0.5 m above the fire to collect the emissions. This test yielded an  
2 emission factor of 27 ng TEQ/kg.

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

6 Collet and Fiani (2006) studied the emissions of PAHs, PCBs, and CDD/CDF emissions  
7 from simulated forest and landfill fires in France. They collected samples from two forests in the  
8 southeast and southwest of France during August, 2003. The samples consisted of litters,  
9 mosses, heathers, brackens, conifer needles, pine cones, shrubs, barks, pine, and oak branches.  
10 The 80 m<sup>3</sup> combustion chamber had an air flow of 1,800 m<sup>3</sup>/hour, corresponding to 22.5 volume  
11 changes per hour, to simulate open burning conditions. Emissions were sampled near the  
12 chamber exit prior to the scrubber and measured in accordance with existing European standards  
13 (EN 1948-1-2-3 for CDD/CDFs and PCBs). For the five simulated forest fire tests, they  
14 estimated these emission factors for CDD/CDFs, in ng I-TEQ/kg: 10.4, 1.02, 25.9, 12.1, and 3.3,  
15 for an average of 10.5 ng I-TEQ/kg. Collet and Fiani also provide emission factors for  
16 12 dioxin-like PCBs, in ng I-TEQ/kg: 0.48, 0.35, 2.34, 0.74, and 0.23, for an average of  
17 0.8 ng I-TEQ/kg. Based on these results they provide a “first estimate” of emissions from forest  
18 fires in France of 28.8 g I-TEQ/year.

19 Using a controlled-burn facility, Gullett and Touati (2003) estimated CDD/CDF  
20 emissions through the testing of three biomass samples collected from the Oregon coast near  
21 Seal Rock and from four biomass samples collected from the North Carolina Piedmont region,  
22 approximately 200 km from the Atlantic coast. The samples generally consisted of equal  
23 portions of live shoots (needles cut from tree branches) and needle litter gathered from the forest  
24 floor. The Oregon samples were composed of pine needles (*Pinus contorta* and *Pinus*  
25 *monticola*) and hemlock needles (*Tyuga heterophylla*); the North Carolina samples were  
26 composed entirely of loblolly pine (*Pinus taeda*). The combustion of these seven samples, piled  
27 approximately 10 cm high, took place on top of an open, flat combustion platform. The average  
28 total TEQ emission factors for the three Oregon samples and the four North Carolina samples  
29 were 15 ng and 25 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg, respectively. Because the waxy cuticle layer on pine  
30 needles has been demonstrated to absorb lipophilic compounds from the atmosphere, Gullett and  
31 Touati (2003) also extracted a raw, as-received Oregon biomass sample to determine whether the

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1 observed emissions were due to simple vaporization of existing CDDs/CDFs or the formation of  
2 new CDDs/CDFs in the combustion process. The CDD/CDF concentration in the sample  
3 measured 1.3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg, which is approximately 20 times lower than the Oregon  
4 CDD/CDF emission factor. The CDD/CDF isomer patterns of the extracted biomass samples  
5 and the emission samples were similar. Therefore, this preliminary evidence suggests CDD/CDF  
6 emissions are not due solely to vaporization of cuticle-bound CDDs/CDFs but are primarily a  
7 result of new formation during forest fires.

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

17 Meyer et al. (2004, 2007) conducted a series of chamber and field tests in Australia to  
18 characterize dioxin emission from a variety of fire types. Five chamber tests were conducted  
19 with forest leaf litter (eucalyptus, box, and ironbark) and producing a mean emission factor of  
20 0.37 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel. A total of 18 forest fire field tests were conducted using  
21 portable high volume air samplers. The field monitors also measured CO<sub>2</sub>, which was related to  
22 combusted biomass and used to calculate emission factors. The field test results are summarized  
23 below:

24

- 25 • Ten prescribed burns in Queensland (coastal forest), Victoria (eucalyptus), and Western  
26 Australia (jarrah forest) with a mean emission factor of 0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.
- 27 • Three fires in tropical savannas with a mean emission factor of 1.1 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg  
28 of fuel.
- 29 • Two wildfires in Victoria (mixed eucalyptus) with a mean emission factor of  
30 0.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.
- 31 • Three woodland fires with a mean emission factor of 1.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.

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## 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<sub>DF</sub>/kg and for the chamber tests is 5.9 ng TEQ<sub>DF</sub>/kg. As discussed below, both types of tests have uncertainties, and the midpoint of this range (3 ng TEQ<sub>DF</sub>/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

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

- 3 • Fire types—A number of different types of fires can occur such as ground fires, which  
4 burn the humus layer of the forest floor but do not burn appreciably above the surface;  
5 surface fires, which burn forest undergrowth and surface litter; and crown fires, which  
6 advance through the tops of trees or shrubs. It is not uncommon for two or three of the  
7 types to occur simultaneously. The ground level monitors cannot directly sample the  
8 high smoke plume generated near the tops of trees during a crown fire. Some of the  
9 smoke generated during a crown fire is present at ground level, but it is uncertain how  
10 representative this smoke is of the main plume. Ground/surface fires create a smoke  
11 plume, which starts near ground level, and the monitors are much more likely to collect  
12 samples, which are representative of these emissions. Similarly, the chamber tests cannot  
13 mimic the intensity and scale of crown fires but may be representative of the conditions  
14 associated with the smaller ground/surface fires.  
15

16 In summary, the forest fire data appear to represent some but not all of the wood types  
17 and fire types that occur in North America. The large database of emission tests suggest a wide  
18 range of emission factors, but this is reasonable considering that they cover a wide variety of  
19 wood types, fire types and burn conditions. The wide range of results increases the confidence  
20 that the full range of emission factors have been characterized and that the midpoint of the range  
21 provides a reasonable central point estimate. On this basis, the emission factor has been  
22 upgraded from preliminary to quantifiable.  
23

### 24 **6.4.3. Air Activity Levels**

25 EPA (2006) derived forest fire activity estimates using data on acres burned per year and  
26 estimates of the amount of biomass per acre. New data for acres burned were found at a  
27 database managed by the National Interagency Fire Center (NIFC) ([www.nifc.gov/fire](http://www.nifc.gov/fire)). These  
28 new data are compared to the previously used data in Table 6-2. The data are generally  
29 comparable except for the wildfire data for 1987 and 1995 where the NIFC data are less than half  
30 the previously used values. These two estimates were changed to reflect these new data. The  
31 amount of biomass burned per acre was assumed to be 9.43 MT/acre for wildfires and  
32 7.44 MT/acre for prescribed burns (Ward et al., 1976). The total forest fire activities were  
33 estimated as 61 MMT in 1987, 55 MMT in 1995 and 243.8 MMT in 2000. A review of the  
34 NIFC historical data on wildfires from 1960 to 2008 suggests that the acres burned in 2000 were  
35 above average and the acres burned in 1987 and 1995 were below average.

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1 **6.4.4. Water Releases**

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

6  
7 **6.4.5. Solid Residue Releases**

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

14 No other direct measures of CDD/CDF content of forest fire ash were found. Wunderli  
15 et al. (1996) determined an average of 10 ng I-TEQ/kg of ash generated for clean wood burned in  
16 stoves. This value is similar to the levels measured by Buckland et al. (1994) in surface soils  
17 after fires and is assumed here for forest fires. UNEP (2005) recommended 4 ng I-TEQ/kg of  
18 material burned (this was derived from an estimate of 200 ng I-TEQ/kg of ash and assumption of  
19 2% ash). This emission factor is assigned a preliminary confidence rating because direct  
20 measurements were available from only one area/fire type and it is unclear if it is representative  
21 of other areas.

22 The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to  
23 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all wood burned.  
24 Multiplying this value by the activity factors discussed above for biomass burned in fires yields  
25 the following: 1.8 MMT in 1987, 1.7 MMT in 1995, and 7.3 MMT in 2000.

26  
27 **6.4.6. Products—None**

28  
29 **6.4.7. Release Summary**

30 The inventory decision criteria and releases to all media are summarized below:  
31

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<b>Inventory Decision Criteria for Forest and Brush Fires</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Forest and Brush Fires</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> <li>• 1995—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> <li>• 2000—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—61 MMT.</li> <li>• 1995—55 MMT.</li> <li>• 2000—243.8 MMT.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—180 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> <li>• 1995—170 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> <li>• 2000—730 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—10 ng I-TEQ<sub>DF</sub>/kg ash (Preliminary).</li> <li>• 1995—10 ng I-TEQ<sub>DF</sub>/kg ash (Preliminary).</li> <li>• 2000—10 ng I-TEQ<sub>DF</sub>/kg ash (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—1.8 MMT ash.</li> <li>• 1995—1.7 MMT ash.</li> <li>• 2000—7.3 MMT ash.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—18 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—17 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—73 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Products</b>
None.

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## **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.

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1 Hirai et al (2003) estimated total CDD/F emission factors from soil measurements at  
2 open burning sites. Soil concentrations in India of 52 pg TEQ/g implied an emission factor over  
3 500 pg TEQ/g of waste. Soil concentrations in Cambodia of 400 pg TEQ/g implied an emission  
4 factor over 4000 pg TEQ/g of waste.

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

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

22 Gonczi et al. (2005) tested emissions from burning domestic wastes in barrels (19 tests)  
23 and open fires (2 tests). Gas collected above these fires allowed for estimation of emission  
24 factors for CDD/CDFs and dioxin-like PCBs for barrel burn and open fire conditions. The  
25 material burned consisted of various mixtures of garden wastes, straw, paper, several forms of  
26 plastic, waste motor oil, RDF, and computer scrap. A barrel burn with a mix of garden waste  
27 and polyvinyl chloride (PVC) waste had the highest emission factor of  
28 96,000 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg burned. The other emission tests ranged from 2.2 to  
29 890 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg burned.

30 The emission factor selected in the original report was 76.8 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg  
31 (72.8 ng I-TEQ<sub>DF</sub>/kg) based on studies by Gullett et al. (1999, 2000) and Lemieux et al. (2000).

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

5 The original report (US EPA, 2006) presented data from six surveys on the prevalence of  
6 backyard trash burning. This data was combined with trash generation rates and Census data on  
7 rural populations to derive national estimates of the amount of trash burned in backyards for each  
8 of the reference years. The original report also described an alternative activity estimate for  
9 2000 developed by OAQPS. The alternative method used similar factors applied on a county by  
10 county basis and made adjustments for amount of waste recycled and influence of open burning  
11 bans. The present report considered the OAQPS method more accurate and adopted it for the  
12 year 2000. This resulted in a 16% increase in activity and a corresponding increase in releases in  
13 2000. No changes were made to the release estimates for 1987 and 1995. All activity estimates  
14 are presented in the release summary below.

### 16 **6.5.2. Solid Residue Releases**

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

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

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

30 The solid residue releases were estimated by multiplying the emission factor and activity  
31 level for each reference year (results shown in summary chart below). It is possible that some of

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1 the ash from barrel burning is taken to municipal waste landfills, but most is probably not.  
2 Therefore, all of these releases are assumed to occur to the open environment.

3

4 **6.5.3. Release Summary**

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

6

<b>Inventory Decision Criteria for Backyard Barrel Burning</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

7

8

<b>Backyard Barrel Burning</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—77 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (73 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—77 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (73 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—77 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (73 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—7.87 MMT.</li> <li>• 1995—8.18 MMT.</li> <li>• 2000—7.79 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—610 g WHO<sub>98</sub> TEQ<sub>DF</sub> (570 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—630 g WHO<sub>98</sub> TEQ<sub>DF</sub> (600 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—600 g WHO<sub>98</sub> TEQ<sub>DF</sub> (570 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—1,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1,600 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 1995—1,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1,600 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> <li>• 2000—1,700 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1,600 ng I-TEQ<sub>DF</sub>/kg) of ash.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—1.2 MMT.</li> <li>• 1995—1.2 MMT.</li> <li>• 2000—1.2 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—2,000 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1,900 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—2,000 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2,000 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—2,000 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1,900 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Products</b>	
None.	

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1 **6.6. RESIDENTIAL YARD WASTE BURNING**

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

3  
4 **6.6.1. Air Releases**

5 Ikeguchi and Tanaka (1999) simulated the open burning of several waste types using a  
6 large furnace with open doors. The flue gas was sampled immediately downstream of the  
7 furnace. One test was conducted with tree and leaf materials. A total of 162.7 kg of this material  
8 were burned in a batch mode lasting 33 minutes. The emission factor was estimated as  
9 4.7 I-TEQ/kg of waste.

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

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

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

26 The studies summarized above had central values ranging from about 4 to  
27 27 ng WHO<sub>98</sub> TEQ/kg of material burned. A midrange value of 10 ng WHO<sub>98</sub> TEQ/kg of  
28 material burned was selected as an overall central estimate.

29 As described in the original report, OAQPS estimated that 255,000 MT of leaf and  
30 255,000 MT of brush (total of 510,000 MT of yard waste) were burned in 2000. Estimates for  
31 1987 and 1995 were derived by assuming that the activities would be proportional to the total

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

3

4 **6.6.2. Water Releases—None**

5

6 **6.6.3. Solid Residue Releases**

7 Hedman et al. (2005) measured an ash emission factor of 0.02 ng WHO<sub>98</sub> TEQ/kg of  
8 waste burned for barrel burning of garden waste. It is assigned a preliminary confidence rating  
9 because it is based on only one waste sample.

10

11 **6.6.4. Products—None**

12

13 **6.6.5. Release Summary**

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

15

<b>Inventory Decision Criteria for Residential Yard Waste Burning</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Residential Yard Waste Burning</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> <li>• 1995—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> <li>• 2000—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—441,000 MT.</li> <li>• 1995—485,000 MT.</li> <li>• 2000—510,000 MT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—4 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> <li>• 1995—5 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> <li>• 2000—5 g WHO<sub>98</sub> TEQ<sub>DF</sub>.</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.02 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of material burned (Preliminary).</li> <li>• 1995—0.02 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of material burned (Preliminary).</li> <li>• 2000—0.02 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of material burned (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—441,000 MT.</li> <li>• 1995—485,000 MT.</li> <li>• 2000—510,000 MT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Products</b>	
None.	

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3

## 4 **6.7. LAND-CLEARING DEBRIS BURNING**

### 5 **6.7.1. Air Releases**

6 The emission factor was changed to correspond to the new forest fire emission factor. No  
7 direct measurements of CDD/CDF emissions from the burning of land-clearing debris have been  
8

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1 performed, so the average emission factor of 3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg, which was used for forest  
2 fires is also used for burning of land-clearing debris. This factor was assumed to apply to all  
3 three reference years. A preliminary confidence rating was assigned to the emission factor  
4 estimate because it was derived from forest fire testing and may not be representative of  
5 land-clearing debris burning.

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

### 10 **6.7.2. Water Releases—None**

### 12 **6.7.3. Solid Residue Releases**

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

17 The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to  
18 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all debris burned.  
19 Multiplying this value by the activity factors discussed above for land clearing debris fires yields  
20 the following: 831,000 MT in 1987, 792,000 MT in 1995, and 852,000 MT in 2000.

### 22 **6.7.4. Release Summary**

23 The inventory decision criteria and releases to all media are summarized below:  
24  
25

<b>Inventory Decision Criteria for Land-Clearing Debris Burning</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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.	Yes		Yes	
Conclusion (Q = Quantitative, P = Preliminary).	P		P	

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<b>Land-Clearing Debris Burning</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 1995—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 2000—3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—27.7 MMT.</li> <li>• 1995—26.4 MMT.</li> <li>• 2000—28.4 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—83 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—79 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—85 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—10 ng I-TEQ<sub>DF</sub>/kg of ash (Preliminary).</li> <li>• 1995—10 ng I-TEQ<sub>DF</sub>/kg of ash (Preliminary).</li> <li>• 2000—10 ng I-TEQ<sub>DF</sub>/kg of ash (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—0.831 MMT ash.</li> <li>• 1995—0.792 MMT ash.</li> <li>• 2000—0.852 MMT ash.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—9 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Products</b>	
None.	

1  
2

### 3 **6.8. UNCONTROLLED COMBUSTION OF POLYCHLORINATED BIPHENYLS**

4           No new studies were found on this topic, and no changes were made to the release  
5 estimate. The use of PCBs in new transformers in the United States is banned, and their use in  
6

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1 existing transformers and capacitors is being phased out under regulations promulgated under the  
2 Toxic Substances Control Act.

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

<b>Uncontrolled Combustion of PCBs</b>
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.

9 **6.9. VOLCANOES**

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

12 **6.10. FIREWORKS**

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

<b>Fireworks</b>
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.

18 **6.11. OPEN BURNING AND OPEN DETONATION OF ENERGETIC MATERIALS**

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

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1 **6.12. UNDERGROUND COAL FIRES**

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

6

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

7

8 **6.13. AGRICULTURAL BURNING**

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

13

14 **6.13.1. Air Releases**

15           Gullett et al. (2006) measured dioxin emission from simulated sugarcane field burns.  
16 Sugarcane leaves from Hawaii and Florida were burned in a manner simulating the natural  
17 physical dimensions and biomass density found during the practice of preharvest field burning.  
18 Eight composite burn tests consisting of 3–33 kg of biomass were conducted, some with  
19 replicate samplers. Emission factor calculations using sampled concentration and measured  
20 mass loss compared well to rigorous carbon balance methods commonly used in field sampling.  
21 The two sources of sugarcane had distinctive emission levels, as did tests on separate seasonal  
22 gatherings of the Florida sugarcane. The average emission factor for two tests of Hawaii  
23 sugarcane was 114 ng TEQ/kg of biomass and for two gatherings of Florida sugarcane was  
24 11 ng TEQ/kg biomass and 2 ng TEQ/kg biomass (these values were originally reported on a  
25 carbon basis and were converted to a total biomass basis by multiplying by 45%).

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

29

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- 1 • Straw—17 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.
- 2 • Sorghum—35 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.
- 3 • Sugar cane—5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.

4  
5 Additionally, two field tests were conducted during sugar cane burning. These tests used  
6 portable high volume air samplers. The field monitors also measured CO<sub>2</sub>, which was related to  
7 combusted biomass and used to calculate emission factors. The emission factor was  
8 1.2 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of fuel.

9 UNEP (2005) recommended an emission factor for agricultural residue burning of  
10 30 ng I-TEQ/kg of material burned (in fields where pesticides or other contaminants are present)  
11 and 0.5 ng I-TEQ/kg of material burned (in fields where pesticides or other contaminants are not  
12 present).

13 In summary, sugar cane chamber tests have produced a very wide range of emission  
14 factors from 2 to 114 ng TEQ/kg. The limited field testing yielded an emission factor of  
15 1 ng TEQ/kg. Accordingly, there is considerable uncertainty about what value is most  
16 representative of U.S. conditions. For the purposes of a preliminary estimate, a value of  
17 10 ng TEQ/kg (rounded geometric mean of range) was selected.

18 Gullett et al. (2006) derived activity estimates for sugar cane burning in the United States  
19 using the following factors: the sugar cane field area for Hawaii, Texas, Louisiana, and Florida; a  
20 biomass production rate of 20 dry tons/ha; and the assumption that 50% of the sugar cane crop  
21 was burned with 90% combustion efficiency. This approach suggests that about 3.5 MMT of  
22 sugar cane were burned. The data were from the 2001–2003 time frame and are assumed here to  
23 apply to 2000. USDA (2009) indicates that sugar cane production increased by about 10% from  
24 1995 to 2000, and a similar amount is assumed for 1987 to 1995. On this basis, the amount of  
25 sugar cane burned in 1987 was 2.8 MMT, and the amount in 1995 was 3.1 MMT. Considering  
26 the multiple assumptions required for this estimate, it is assigned a preliminary confidence  
27 rating.

### 28 **6.13.2. Water Releases—None**

29  
30

1 **6.13.3. Solid Residue Releases**

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

11  
12 **6.13.4. Products—None**

13  
14 **6.13.5. Release Summary**

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

16

<b>Inventory Decision Criteria for Sugar Cane Burning</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Sugar Cane Burning</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> <li>• 1995—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> <li>• 2000—10 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—2.8 MMT (Preliminary).</li> <li>• 1995—3.1 MMT (Preliminary).</li> <li>• 2000—3.5 MMT (Preliminary).</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—28 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—31 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—35 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> <li>• 1995—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> <li>• 2000—0.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of biomass (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—2.8 MMT (Preliminary).</li> <li>• 1995—3.1 MMT (Preliminary).</li> <li>• 2000—3.5 MMT (Preliminary).</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>	
<b>Products</b>	
None.	

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## 5 **6.14. OPEN BURNING DEMOLITION/CONSTRUCTION WOOD**

### 6 **6.14.1. Air Releases**

7 This is a new section. No direct measurements of CDD/CDF emissions from the open  
8 burning of demolition/construction wood were found. However, this activity involves similar

9

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1 material as burned in structural fires. As discussed in Section 6.2.1, the presence of  
2 manufactured boards and treated lumber in structures is expected to increase dioxin emissions  
3 relative to the combustion of untreated natural wood. Section 6.2.1 derived a structural fire  
4 emission factor of 32  $\mu\text{g I-TEQ}/\text{fire}$  by averaging data from Carroll (1996) and Thomas and  
5 Spiro (1995) and converting to a mass basis by dividing by a default fuel-loading factor for  
6 structural fires of 1.15 tons/fire (ERG, 2001), yielding 28 ng I-TEQ/kg. This factor was assumed  
7 to apply to the open burning of demolition/construction wood for all three reference years. A  
8 preliminary confidence rating was assigned to the emission factor estimate because it was  
9 derived from structural fire estimates that were considered preliminary.

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

#### 16 **6.14.2. Water Releases—None**

#### 18 **6.14.3. Solid Residue Releases**

19 As discussed in Section 6.2, an ash emission factor of 300 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg of  
20 material burned was developed for structural fires and is adopted here for ash from open burning  
21 of construction/demolition wood. A preliminary confidence rating was assigned to the emission  
22 factor estimate because it was derived from structural fire estimates.

23 The ash yield from wood grown in temperate zones is 0.1 to 1%, and bark produces 3 to  
24 8% ash (Ragland et al., 1991). A midrange value of 3% is assumed here for all wood burned.  
25 Multiplying this value by the activity factors discussed above for open burning of  
26 construction/demolition wood yields the following: 0.024 MMT in all reference years. These are  
27 given a preliminary confidence rating because they are derived from emission factors with  
28 preliminary confidence ratings.

#### 30 **6.14.4. Release Summary**

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

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<b>Inventory Decision Criteria for Open Burning Demolition/Construction Wood</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Open Burning Demolition/Construction Wood</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 1995—28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 2000—28 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—0.8 MMT (Preliminary).</li> <li>• 1995—0.8 MMT (Preliminary).</li> <li>• 2000—0.8 MMT (Preliminary).</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—22 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—22 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—22 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—300 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 1995—300 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> <li>• 2000—300 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—0.024 MMT (Preliminary).</li> <li>• 1995—0.024 MMT (Preliminary).</li> <li>• 2000—0.024 MMT (Preliminary).</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—7 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Products</b>	
None.	

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### 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.

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

5

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

6

7

## 8 **6.16. CANDLE BURNING**

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

13

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

14

15

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

<b>Biomass description and location</b>	<b>Wood type</b>	<b>Test device</b>	<b><i>n</i></b>	<b>ng TEQ<sub>DF</sub>/kg of biomass Mean (Range)</b>	<b>Reference</b>
Tree from Central North Carolina	Loblolly pine	Chamber	7	0.86 <sup>a</sup>	Gullett et al. (2008)
Pile—Central North Carolina	Loblolly pine	Chamber	10	0.615 <sup>a</sup>	Gullett et al. (2008)
Supplement—Central North Carolina	Loblolly pine	Chamber	2	0.93 <sup>a</sup>	Gullett et al. (2008)
Supplement—Western North Carolina	White pine	Chamber	2	1.225 <sup>a</sup>	Gullett et al. (2008)
Supplement—Oregon	Hemlock/Pine	Chamber	2	1.64 <sup>a</sup>	Gullett et al. (2008)
Shrub—California	Titi, pine straw, gallberry	Chamber	2	8.36 <sup>a</sup>	Gullett et al. (2008)
Shrub—Florida	Maritime chaparral	Chamber	2	2.62 <sup>a</sup>	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)**

<b>Biomass description and location</b>	<b>Wood type</b>	<b>Test device</b>	<b><i>n</i></b>	<b>ng TEQ<sub>DF</sub>/kg of biomass Mean (Range)</b>	<b>Reference</b>
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) <sup>a</sup>	Meyer et al. (2004, 2007)
Tropical savanna—Australia	Unspecified	Field	3	1.1 (0.2–2.8) <sup>a</sup>	Meyer et al. (2004, 2007)
Wildfires in Victoria	Eucalyptus	Field	2	0.7 (0.6–0.8) <sup>a</sup>	Meyer et al. (2004, 2007)
Woodlands in Australia	Unspecified	Field	3	1.5 (0.9–2.5) <sup>a</sup>	Meyer et al. (2004, 2007)

<sup>a</sup>Originally reported as ng TEQ/kg of carbon and converted to ng TEQ/kg of biomass by multiplying by 0.5.

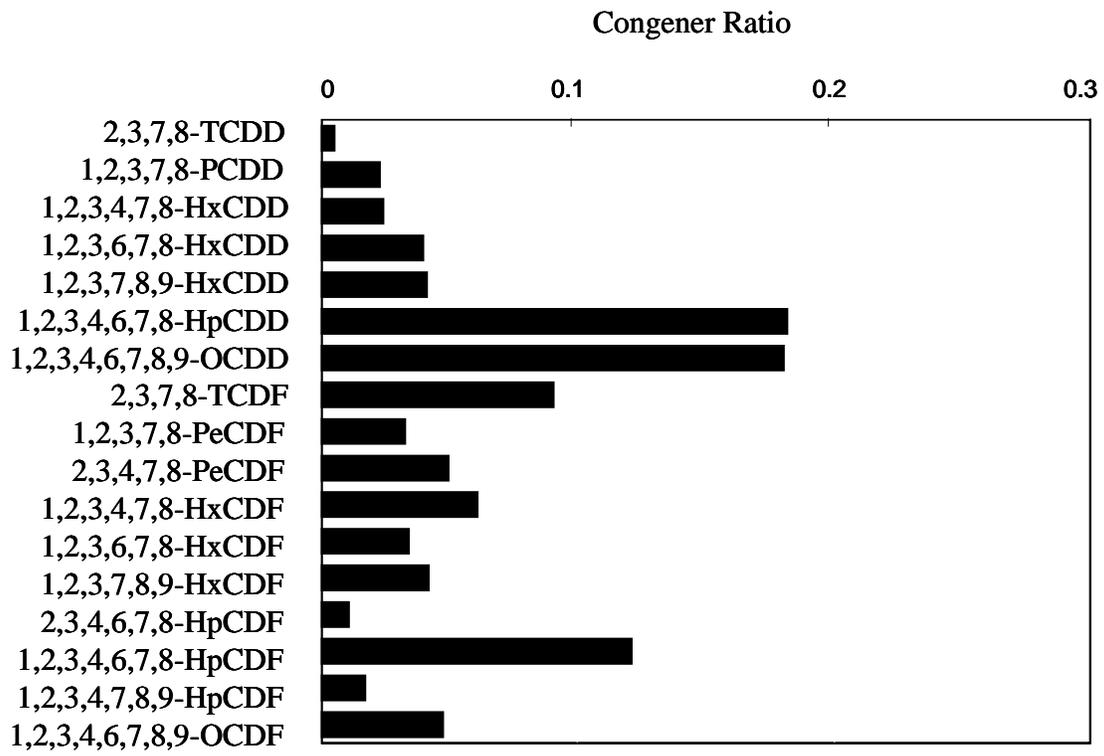
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**Table 6-2. Comparison of Forest Fire Data (million acres burned/year)**

<b>Fire type and year</b>	<b>CEQ, 1997</b>	<b>U.S. EPA, 2002d</b>	<b>NIFC, 2009</b>
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

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NA= Not Available.



Source: Pleil and Lorber (2007)

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**Figure 6-1. Congener profile for structure fires.**

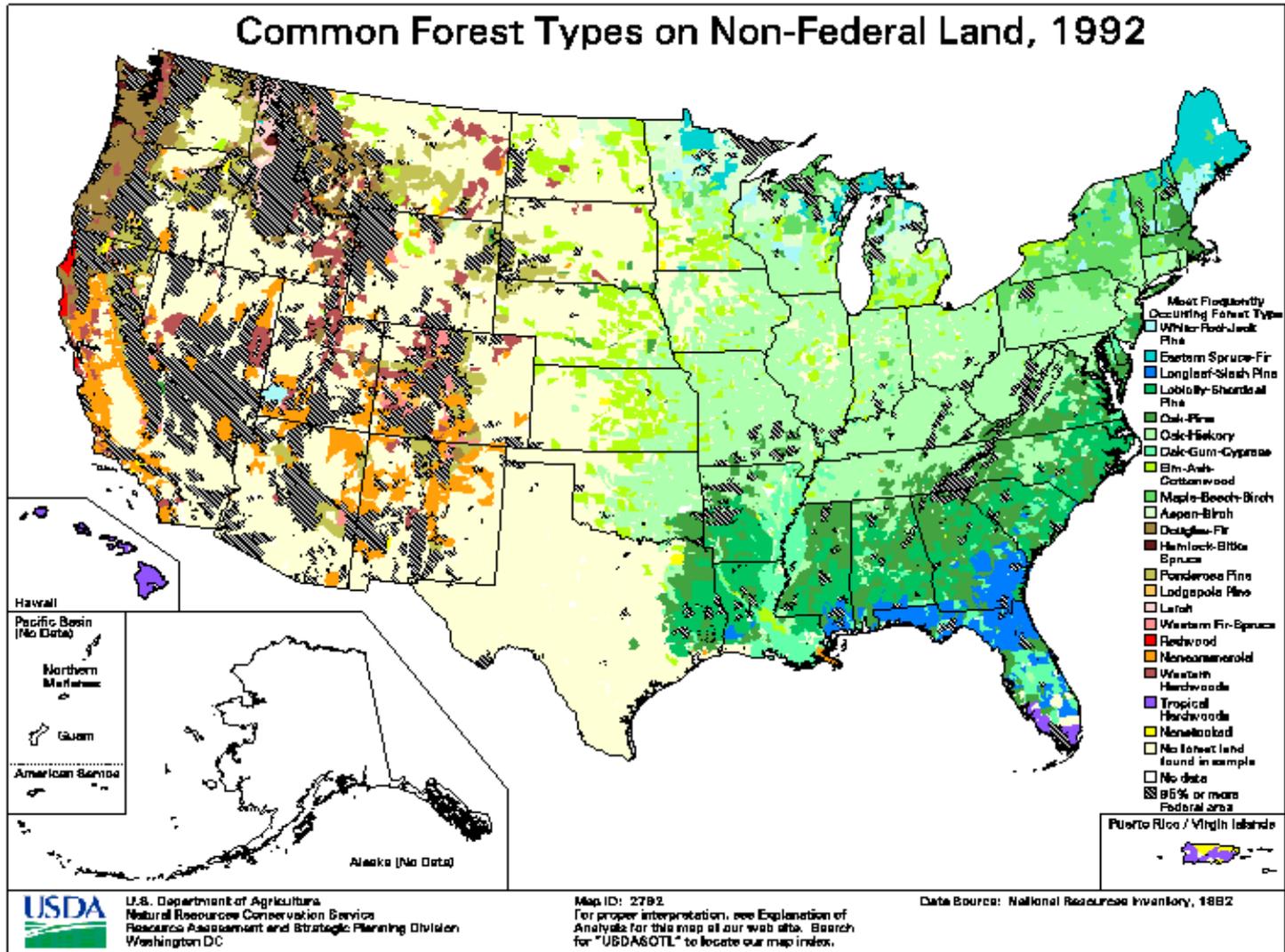


Figure 6-2. Forest fire types in the United States.

1                   **7. METAL SMELTING AND REFINING SOURCES OF CDD/CDFS**  
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4                   This chapter addresses dioxin releases associated with primary and secondary metal  
5 processing. Primary processes involve the extraction of the base metal from mineral ores.  
6 Secondary processes extract the base metal from recycled or waste materials.  
7

8                   **7.1. PRIMARY NONFERROUS METAL SMELTING/REFINING**

9                   **7.1.1. Primary Copper Smelting and Refining**

10                   Minor changes were made to the air-release estimates.  
11

12                   **7.1.1.1. Air Releases**

13                   The emission factor was derived from testing at two facilities by Environmental Risk  
14 Sciences, Inc. (1995), who used stack testing results to calculate the annual TEQ emission to air  
15 to be less than 0.5 g I-TEQ<sub>DF</sub> in 1995 for the seven facilities (out of a total of eight) belonging to  
16 the National Mining Association. Using the activity level presented below of 1.60 MMT for  
17 1995, the emission factor is calculated to be 0.31 ng I-TEQ<sub>DF</sub>/kg of copper. This emission factor  
18 was applied to all three reference years.

19                   In 1987, copper refineries produced 1.13 MMT of copper (USGS, 1997a). In 1995,  
20 eight primary copper smelters were in operation in the United States; one of which closed at the  
21 end of that year (Edelstein, 1995). Total refinery production was 1.60 MMT in 1995, including  
22 0.36 MMT from scrap material (Edelstein, 1995). In 2000, four primary smelters of copper were  
23 in operation in the United States, producing 1.61 MMT of copper (USGS, 2002a).  
24

25                   **7.1.1.2. Water Releases**

26                   No information was found on water releases from these facilities.  
27

28                   **7.1.1.3. Solid Residue Releases**

29                   Although no measurement data were found, CDD/CDFs are likely to be present in the fly  
30 ash and possibly other solid residues at these facilities because they have been found in the air

1 emissions. These residues are disposed in landfills and, therefore, are not considered to be an  
2 environmental release.

3

4 **7.1.1.4. Products**

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

7

8 **7.1.1.5. Release Summary**

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

10

<b>Inventory Decision Criteria for Primary Copper Smelting and Refining</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

11

12

<b>Primary Copper Smelting and Refining</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.31 ng I-TEQ<sub>DF</sub>/kg of copper.</li> <li>• 1995—0.31 ng I-TEQ<sub>DF</sub>/kg of copper.</li> <li>• 2000—0.31 ng I-TEQ<sub>DF</sub>/kg of copper.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—1.13 MMT of copper.</li> <li>• 1995—1.60 MMT of copper.</li> <li>• 2000—1.61 MMT of copper.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—0.3 g I-TEQ.</li> <li>• 1995—0.5 g I-TEQ.</li> <li>• 2000—0.5 g I-TEQ.</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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### 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<sub>98</sub> 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

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1 considered preliminary. The activity estimates were derived from production data from the  
2 U.S. Geological Society (USGS, 2002).

3 Under the EPA TRI program for 2000, this facility reported air releases of  
4 623 g CDD/CDFs (3.3 g WHO<sub>98</sub> TEQ<sub>DF</sub>) and on-site surface impoundments of  
5 1,661 g CDD/CDFs (8.3 g WHO<sub>98</sub> TEQ<sub>DF</sub>) (U.S. EPA, 2008). No releases to other media were  
6 reported. As explained in Chapter 1, the accuracy of the TRI data is unknown, and, therefore,  
7 they are not used to make quantitative estimates in this document but rather as supportive  
8 evidence that releases do occur.

9

#### 10 **7.1.2.2. Water Releases**

11 Monitoring of wastewater discharges from U.S. magnesium production facilities for  
12 CDD/CDF content has not been reported. Wastewater discharges of CDDs/CDFs reported for  
13 the Norwegian facility (Oehme et al., 1989) are not adequate to support development of  
14 wastewater emission factors for U.S. facilities because of possible differences in the processes  
15 used to manufacture MgCl<sub>2</sub> and pollution control equipment. Therefore, water releases are  
16 possible but could not be quantified.

17

#### 18 **7.1.2.3. Solid Residue Releases**

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

23

#### 24 **7.1.2.4. Release Summary**

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

26

<b>Inventory Decision Criteria for Primary Magnesium Smelting and Refining</b>	
	<b>Air Water Solids Products</b>
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 <sup>a</sup>

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<sup>a</sup>Preliminary for 1987 and 1995, Quantitative for 2000 because testing occurred at only facility operating in 2000.

<b>Primary Magnesium Smelting and Refining</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—94 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (110 ng I-TEQ<sub>DF</sub>/kg). (Preliminary)</li> <li>• 1995—94 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (110 ng I-TEQ<sub>DF</sub>/kg). (Preliminary)</li> <li>• 2000—94 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (110 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.142 MMT.</li> <li>• 1995—0.142 MMT.</li> <li>• 2000—0.083 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—13 g WHO<sub>98</sub> TEQ<sub>DF</sub> (16 g I-TEQ<sub>DF</sub>). (Preliminary)</li> <li>• 1995—13 g WHO<sub>98</sub> TEQ<sub>DF</sub> (16 g I-TEQ<sub>DF</sub>). (Preliminary)</li> <li>• 2000—8 g WHO<sub>98</sub> TEQ<sub>DF</sub> (9 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
Releases are possible but could not be quantified.	
<b>Solid Residue Releases</b>	
Releases are possible but could not be quantified.	
<b>Products</b>	
None.	

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1  
2 **7.1.3. Primary Nickel Smelting and Refining**

3 No changes were made in the release estimates from these facilities.  
4

5 **7.1.3.1. Air Releases**

6 The emissions information contained in the Norwegian study (Oehme et al., 1989) is not  
7 adequate to support development of emission factors for the U.S. facility for 1987 and 1995.  
8 Since the only U.S. facility closed in 1998, emissions for 2000 are zero.  
9

10 **7.1.3.2. Water Releases**

11 EPA (2006) reports that one study (Oehme et al., 1989) measured CDD/CDFs in  
12 wastewater releases from a nickel production plant in Norway. The information is not adequate  
13 to support development of emission factors for the United States. Thus, releases are possible but  
14 could not be quantified in 1987 and 1995. Since the only U.S. facility closed in 1998, emissions  
15 for 2000 are zero.  
16

17 **7.1.3.3. Solid Residue Releases**

18 No information was found indicating that CDD/CDFs were present in solid residues from  
19 these facilities.  
20

21 **7.1.3.4. Products**

22 No information was found indicating that CDD/CDFs were present in products from  
23 these facilities.  
24

25 **7.1.3.5. Release Summary**

26 The release estimates are summarized below:  
27

<b>Primary Nickel Smelting and Refining</b>
<b>Air Releases</b>
Releases are possible but could not be quantified in 1987 and 1995 and were zero in 2000.
<b>Water Releases</b>
Releases are possible but could not be quantified in 1987 and 1995 and were zero in 2000.
<b>Solid Residue Releases</b>
None.
<b>Products</b>
None.

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**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

1 were less than 1 g WHO<sub>98</sub> TEQ<sub>DF</sub>. A total of 240 g WHO<sub>98</sub> TEQ<sub>DF</sub> were disposed in landfills  
2 (U.S. EPA, 2008). No releases to other media were reported. As explained in Chapter 1, the  
3 accuracy of the TRI data is unknown, and therefore, they are not used to make quantitative  
4 estimates in this document but rather as supportive evidence that releases do occur.

#### 6 **7.1.5.1. Air Releases**

7 Based on the TRI data reported above, air releases are possible but could not be  
8 quantified.

#### 10 **7.1.5.2. Water Releases**

11 Based on the TRI data reported above, water releases are possible but could not be  
12 quantified.

#### 14 **7.1.5.3. Solid Residue Releases**

15 Titanium dioxide production creates a variety of sludge wastes, which can contain  
16 CDDs/CDFs. As discussed above, the TRI data suggest that inorganic pigment facilities  
17 disposed a total of 240 g WHO<sub>98</sub> TEQ<sub>DF</sub> in landfills in 2000 (U.S. EPA, 2008).

18 EPA (2001) reports the following measurements in wastes generated in conjunction with  
19 chlorinators:

- 21 • Millennium Baltimore, chloride solids/waste acid: 812 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/L.
- 22 • Millennium Baltimore, filter press solids: 2,615 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.
- 23 • DuPont Edge Moor, iron rich: 58.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.
- 24 • DuPont New Johnsonville, wastewater treatment solids: 402 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.

25  
26 EPA (2001) reports that the production of wastewater treatment sludges from comingled chloride  
27 and sulfate process wastewaters at the Millennium Plant was 93,121 MT/year. Combining this  
28 production rate with an assumed 1,000 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg suggests that about  
29 90 g WHO<sub>98</sub> TEQ<sub>DF</sub>/year may be associated with these sludges at this plant.

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1 For the most part, these sludges have been disposed of in either on-site or off-site RCRA  
 2 Subtitle D solid waste disposal facilities. However, given the potential for leaching of the heavy  
 3 metals from the sludge in the Subtitle D landfill, EPA has listed this waste as hazardous waste  
 4 under Subtitle C. These sludges are now considered a hazardous waste under RCRA and must  
 5 be disposed of in permitted landfills (U.S. EPA, 2001). These amounts are not considered to  
 6 cause environmental releases under the definition in this document.

7  
 8 **7.1.5.4. Products**

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

11  
 12 **7.1.5.5. Release Summary**

13 The release estimates are summarized below:

<b>Primary Titanium Smelting and Refining</b>
<b>Air Releases</b>
Not quantifiable.
<b>Water Releases</b>
Not quantifiable.
<b>Solid Residue Releases</b>
None.
<b>Products</b>
None.

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 17 **7.2. SECONDARY NONFERROUS METAL SMELTING AND REFINING**

18 **7.2.1. Secondary Aluminum Smelting and Refining**

19 No changes were made in the release estimates from these facilities, but some additional  
 20 background information is provided below.

1 **7.2.1.1. Air Releases**

2 The emission factors were derived from testing at seven facilities (CARB, 1992a, b; U.S.  
3 EPA, 1995c). Activity data were based on survey information from USGS (2002a).

4 In the year 2000, 29 facilities with an SIC code for secondary smelting and refining of  
5 nonferrous metals reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). Most  
6 of these facilities appeared to be aluminum producers. The sum of the air releases across these  
7 facilities was 1,022 g, which EPA estimates is equal to 13.8 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to  
8 other media were reported. As explained in Chapter 1, the TRI data are not used to make  
9 quantitative estimates in this document but rather as supportive evidence that releases do occur.

10

11 **7.2.1.2. Water Releases**

12 No information was found indicating that CDD/CDFs were present in water releases from  
13 these facilities.

14

15 **7.2.1.3. Solid Residue Releases**

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

20

21 **7.2.1.4. Products**

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

24

25 **7.2.1.5. Releases**

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

27

<b>Inventory Decision Criteria for Secondary Aluminum Smelting and Refining</b>	
	<b>Air Water Solids Products</b>
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

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<b>Secondary Aluminum Smelting and Refining</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—15 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (14 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—15 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (14 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—5.2 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (4.9 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.7 MMT.</li> <li>• 1995—1.3 MMT.</li> <li>• 2000—1.6 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—11 g WHO<sub>98</sub> TEQ<sub>DF</sub>(10 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—20 g WHO<sub>98</sub> TEQ<sub>DF</sub>(18 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—8 g WHO<sub>98</sub> TEQ<sub>DF</sub>(8 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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### 7.2.2. Secondary Copper Smelting and Refining

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

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1 **7.2.2.1. Air Releases**

2 Only three facilities were active during the reference years. The emission factors were  
3 derived from stack testing at these plants as described in US EPA (2006). The release summary  
4 below shows the emission factor and activity estimates (based on data for each plant) in each  
5 reference year.

6  
7 **7.2.2.2. Water Releases**

8 No information was found indicating that CDD/CDFs were present in water releases from  
9 these facilities.

10  
11 **7.2.2.3. Solid Residue Releases**

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

16  
17 **7.2.2.4. Products**

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

20  
21 **7.2.2.5. Releases**

22 The inventory decision criteria and releases to all media are summarized below:  
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<b>Inventory Decision Criteria for Secondary Copper Smelting and Refining</b>	
	<b>Air    Water    Solids    Products</b>
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

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<b>Secondary Copper Smelting and Refining</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<i>Franklin</i>	
<ul style="list-style-type: none"> <li>• 1987—17,000 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (17,000 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—17,000 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (17,000 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Chemetco</i>	
<ul style="list-style-type: none"> <li>• 1987—3.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3.6 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—3.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3.6 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—3.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3.66 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Gaston</i>	
<ul style="list-style-type: none"> <li>• 1987—8,900 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (8,700 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<i>Franklin</i>	
<ul style="list-style-type: none"> <li>• 1987—13,600,000 kg.</li> <li>• 1995—16,000,000 kg.</li> </ul>	
<i>Chemetco</i>	
<ul style="list-style-type: none"> <li>• 1987—120,000,000 kg.</li> <li>• 1995—135,000,000 kg.</li> <li>• 2000—235,000,000 kg.</li> </ul>	
<i>Gaston</i>	
<ul style="list-style-type: none"> <li>• 1987—85,000,000 kg.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—990 g WHO<sub>98</sub> TEQ<sub>DF</sub> (970 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—270 g WHO<sub>98</sub> TEQ<sub>DF</sub> (270 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—0.9 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.8 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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### 7.2.3. Secondary Lead Smelting

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

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**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:

<b>Inventory Decision Criteria for Secondary Lead Smelting</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Secondary Lead Smelting</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<i>Blast furnaces without scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000— 8.8 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (8.3 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Blast furnaces with scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000—0.64 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.63 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Reverberatory and colocated furnaces without scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000—0.42 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.41 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Reverberatory and colocated furnaces with scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000—0.05 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.05 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Rotary furnaces without scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000—0.66 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.66 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<i>Rotary furnaces with scrubber</i>	
<ul style="list-style-type: none"> <li>• 1987, 1995, 2000—0.24 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (0.24 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>	
<b>Activity Levels</b>	
<i>Blast furnaces (14% with and 86% without scrubbers)</i>	
<ul style="list-style-type: none"> <li>• 1987—0.15 MMT.</li> <li>• 1995—0.2 MMT.</li> <li>• 2000—0.29 MMT.</li> </ul>	
<i>Reverberatory and colocated furnaces (52% with and 48% without scrubbers)</i>	
<ul style="list-style-type: none"> <li>• 1987—0.53 MMT.</li> <li>• 1995—0.72 MMT.</li> <li>• 2000—1 MMT.</li> </ul>	
<i>Rotary furnaces (57% with and 43% without scrubbers)</i>	
<ul style="list-style-type: none"> <li>• 1987—0.04 MMT.</li> <li>• 1995—0.05 MMT.</li> <li>• 2000—0.07 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—1 g WHO<sub>98</sub> TEQ<sub>DF</sub> (1 g I-TEQ<sub>DF</sub>).</li> <li>• 1995— 2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (2 g I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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**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.

1 The secondary slab zinc production in the United States was 82,500 MT in 1987,  
2 131,000 MT in 1995 and 135,000 MT in 2000 (USGS, 2009b).

3  
4 **7.2.4.2. Water Releases**

5 No information was found indicating that CDD/CDFs were present in water releases from  
6 these facilities.

7  
8 **7.2.4.3. Solid Residue Releases**

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

13  
14 **7.2.4.4. Products**

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

17  
18 **7.2.4.5. Releases**

19 The inventory decision criteria and releases to all media are summarized below:  
20

<b>Inventory Decision Criteria for Secondary Zinc Production</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Secondary Zinc Production</b>	
<b>Air Releases</b>	
<b>Emission Factor</b>	<ul style="list-style-type: none"> <li>• 1987—50 ng I-TEQ/kg of zinc.</li> <li>• 1995—50 ng I-TEQ/kg of zinc.</li> <li>• 2000—50 ng I-TEQ/kg of zinc.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—82,500 MT.</li> <li>• 1995—131,000 MT.</li> <li>• 2000—135,000 MT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—4 g I-TEQ.</li> <li>• 1995—7 g I-TEQ.</li> <li>• 2000—7 g I-TEQ.</li> </ul>
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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**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.

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1 **7.3.1.2. Water Releases**

2 No information was found indicating that CDD/CDFs were present in water releases from  
3 these facilities.

4  
5 **7.3.1.3. Solid Residue Releases**

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

10  
11 **7.3.1.4. Products**

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

14  
15 **7.3.1.5. Releases**

16 The inventory decision criteria and releases to all media are summarized below:  
17

<b>Inventory Decision Criteria for Sinter Production</b>	
	<b>Air Water Solids Products</b>
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

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1 **7.3.2.1. Air Releases**

2 US EPA (2006) used the emission factor of 0.23 ng I-TEQ<sub>DF</sub>/kg of coal consumed  
3 estimated by Bremmer, et al. (1994). Another study measured dioxin emissions at four Canadian  
4 facilities (Charles E. Napier Company, Ltd., 2000). The present study averages the emission  
5 factor across the facilities tested in both studies to derive an emission factor of  
6 0.29 ng I-TEQ<sub>DF</sub>/kg of coal consumed. This emission factor was applied to all three reference  
7 years. Coke production estimates were obtained from EIA (2002). The confidence rating was  
8 upgraded from preliminary to quantitative because the emission factor was derived from two  
9 studies involving 5 facilities.

10 In the year 2000, four facilities with an SIC code for steel works, blast furnaces  
11 (including coke ovens), and rolling mills reported dioxin releases under the EPA TRI program  
12 (U.S. EPA, 2008). The sum of the air releases across these facilities was 31.8 g, which EPA  
13 estimates is equal to 4.1 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were reported. As  
14 explained in Chapter 1, the TRI data are not used to make quantitative estimates in this document  
15 but rather as supportive evidence that releases do occur.

16  
17 **7.3.2.2. Water Releases**

18 Although water is used in quench towers to cool hot coke, it is recycled, and the  
19 evaporate is replenished. Therefore no water releases occur.

20  
21 **7.3.2.3. Solid Residue Releases**

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

26  
27 **7.3.2.4. Products**

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

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1 **7.3.2.5. Release Summary**

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

<b>Inventory Decision Criteria for Coke Production</b>	
	<b>Air Water Solids Products</b>
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

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<b>Coke Production</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.29 ng I-TEQ<sub>DF</sub>/kg of coal.</li> <li>• 1995—0.29 ng I-TEQ<sub>DF</sub>/kg of coal.</li> <li>• 2000—0.29 ng I-TEQ<sub>DF</sub>/kg of coal.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—33.5 MMT.</li> <li>• 1995—29.9 MMT.</li> <li>• 2000—26.2 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—10 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—9 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—8 g I-TEQ<sub>DF</sub>.</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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**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<sub>98</sub> 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:

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<b>Inventory Decision Criteria for Secondary Ferrous Metal Smelting/Refining</b>	
	<b>Air Water Solids Products</b>
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

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<b>Secondary Ferrous Metal Smelting/Refining</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—1.2 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of steel.</li> <li>• 1995—1.2 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of steel.</li> <li>• 2000—1.2 ng (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>/kg) of steel.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—30.8 MMT.</li> <li>• 1995—38.4 MMT.</li> <li>• 2000—49.0 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—37 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 1995—46 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> <li>• 2000—59 g (WHO<sub>98</sub> or I-TEQ<sub>DF</sub>).</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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1 **7.5. FERROUS FOUNDRIES**

2 No changes were made to the release estimates for these facilities, but some additional  
3 background information is provided below.

4  
5 **7.5.1. Air Releases**

6 The emission factor for the ferrous foundries was estimated by combining the mean  
7 emission factor derived from the data reported in Umweltbundesamt (1996), CARB (1993), and  
8 EPA (1997a), yielding a value of 1.23 ng I-TEQ<sub>DF</sub>/kg of metal feed. This was converted to  
9 1.37 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg based on the congener profile reported in EPA, 1997a. The emission  
10 data represent a total of 10 facilities and generated emission factors ranging over 4 orders of  
11 magnitude. Based on the inconsistency of these results for reasons that are not clear, the release  
12 estimates are considered preliminary. The activity estimates were derived from survey data from  
13 USGS (2001).

14 In the year 2000, five facilities with an SIC code for gray and ductile iron foundries  
15 reported dioxin releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air  
16 releases across these facilities was 117 g, which EPA estimates is equal to 21.5 g WHO<sub>98</sub> TEQ<sub>DF</sub>.  
17 No releases to other media were reported. As explained in Chapter 1, the TRI data are not used  
18 to make quantitative estimates in this document but rather as supportive evidence that releases do  
19 occur.

20  
21 **7.5.2. Water Releases**

22 Liquid pollution makes up a small portion of the total waste stream from foundries  
23 (Freeman, 1995). Water is used in foundries to cool metal and other work pieces and in the wet  
24 scrubber air emission system. No information was found on CDD/CDF levels in these  
25 wastewaters.

26  
27 **7.5.3. Solid Residue Releases**

28 Solid waste makes up a large portion of the pollution from foundries. One-quarter to  
29 one ton of solid waste per one ton of castings is expected (Shah, 1995). The waste comes from

1 sand, slag, emissions control dust, and spent refractories. Molding and core sand make up  
2 66–88% of the total waste from ferrous foundries (U.S. EPA, 1992b).

3 Slag waste is often very complex chemically and contains a variety of contaminants from  
4 the scrap metals. Common components include metal oxides, melted refractories, sand, and coke  
5 ash (if coke is used). Fluxes may also be added to help remove the slag from the furnace. Slag  
6 may be hazardous if it contains lead, cadmium, or chromium from steel or nonferrous metals  
7 melting. Iron foundry slag may be highly reactive if calcium carbide is used to desulfurize the  
8 iron. No information was found on CDD/CDF levels in these solid wastes. However, they are  
9 typically landfilled and thus not considered a release to environment.

10

#### 11 **7.5.4. Products**

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

14

#### 15 **7.5.5. Release Summary**

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

17

<b>Inventory Decision Criteria for Ferrous Foundries</b>	
	<b>Air Water Solids Products</b>
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

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<b>Ferrous Foundries</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—1.4 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.2 ng I-TEQ<sub>DF</sub>/kg) of metal feed. (Preliminary)</li> <li>• 1995—1.4 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.2 ng I-TEQ<sub>DF</sub>/kg) of metal feed. (Preliminary)</li> <li>• 2000—1.4 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1.2 ng I-TEQ<sub>DF</sub>/kg) of metal feed. (Preliminary)</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—9.19 MMT.</li> <li>• 1995—13.9 MMT.</li> <li>• 2000—11.3 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—13 g WHO<sub>98</sub> TEQ<sub>DF</sub> (11 g I-TEQ<sub>DF</sub>). (Preliminary)</li> <li>• 1995—19 g WHO<sub>98</sub> TEQ<sub>DF</sub> (17 g I-TEQ<sub>DF</sub>). (Preliminary)</li> <li>• 2000—16 g WHO<sub>98</sub> TEQ<sub>DF</sub> (14 g I-TEQ<sub>DF</sub>). (Preliminary)</li> </ul>	
<b>Water Releases</b>	
None.	
<b>Solid Residue Releases</b>	
None.	
<b>Products</b>	
None.	

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**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

1 that foundry production was a constant ratio with total consumption: 82,500 MT in 1995 and  
2 72,000 MT in 1987.

3 Foundries typically have solid waste associated with residues from the casting process.  
4 No information was found on CDD/CDF levels in these materials. However, these residues  
5 would be landfilled and, therefore, are not considered an environmental release.

6 The inventory decision criteria and releases to all media are summarized below:  
7

<b>Inventory Decision Criteria for Aluminum Foundries</b>	
	<b>Air Water Solids Products</b>
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

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9

<b>Aluminum Foundries</b>
<b>Air Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—3.5 ng I-TEQ<sub>DF</sub>/kg of metal feed (Preliminary).</li> <li>• 1995—3.5 ng I-TEQ<sub>DF</sub>/kg of metal feed (Preliminary).</li> <li>• 2000—3.5 ng I-TEQ<sub>DF</sub>/kg of metal feed (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—72,000 MT.</li> <li>• 1995—82,500 MT.</li> <li>• 2000—95,600 MT.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—0.3 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—0.3 g I-TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—0.3 g I-TEQ<sub>DF</sub> (Preliminary).</li> </ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
None.
<b>Products</b>
None

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**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:

1

<b>Inventory Decision Criteria for Aluminum Foundries</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

2

3

<b>Copper Foundries</b>				
<b>Air Releases</b>				
<b>Emission Factors</b>				
<ul style="list-style-type: none"> <li>• 1987—0.03 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> <li>• 1995—0.03 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> <li>• 2000—0.03 ng I-TEQ<sub>DF</sub>/kg of metal feed.</li> </ul>				
<b>Activity Levels</b>				
<ul style="list-style-type: none"> <li>• 1987—72,000 MT.</li> <li>• 1995—82,500 MT.</li> <li>• 2000—95,600 MT.</li> </ul>				
<b>Releases</b>				
<ul style="list-style-type: none"> <li>• 1987—&lt;0.1 g I-TEQ<sub>DF</sub>.</li> <li>• 1995—&lt;0.1 g I-TEQ<sub>DF</sub>.</li> <li>• 2000—&lt;0.1 g I-TEQ<sub>DF</sub>.</li> </ul>				
<b>Water Releases</b>				
None.				
<b>Solid Residue Releases</b>				
None.				
<b>Products</b>				
None.				

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1  
2 **7.7. SCRAP ELECTRIC WIRE RECOVERY**

3 No changes were made in the release estimates for these facilities. It is unknown how  
4 many facilities in the United States conducted scrap wire recovery operations over the reference  
5 years, so no activity estimates could be made, and therefore, no release estimates could be made  
6 as well.

7  
8 **7.7.1. Air Releases**

9 As reported in EPA (2006), CDDs/CDFs have been measured in the emissions from these  
10 facilities. The emission factor from EPA (1987) of 15.8 ng WHO<sub>98</sub> TEQ<sub>DF</sub> (16.9 ng I-TEQ<sub>DF</sub>/kg)  
11 of scrap feed was applied to all reference years. This factor is considered preliminary because it  
12 is based on testing at only one facility. Lacking activity information on these facilities; however,  
13 no estimates of air releases can be made.

14  
15 **7.7.2. Water Releases**

16 No information was found indicating that these facilities have water effluents.

17  
18 **7.7.3. Solid Residue Releases**

19 Ash is produced as a byproduct when scrap wire is combusted. Harnly et al. (1995)  
20 analyzed soil/ash mixtures from three closed metal recovery facilities and from three closed sites  
21 using open burning for copper recovery near a California desert town. The geometric means of  
22 the total CDD/CDF concentrations at the facility sites and the open burning sites were 86,000  
23 and 48,500 ng/kg, respectively. The geometric mean TEQ concentrations were 2,900 and  
24 1,300 ng I-TEQ<sub>DF</sub>/kg, respectively. A significantly higher geometric mean concentration  
25 (19,000 ng I-TEQ<sub>DF</sub>/kg) was found in fly ash located at two of the facility sites. Lacking activity  
26 information on these facilities, no estimates of releases from solid residues can be made. The  
27 portion of the ash that is disposed in landfills would not be considered an environmental release.

28  
29 **7.7.4. Products**

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

3 **7.7.5. Release Summary**

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

5

<b>Scrap Electric Wire Recovery</b>
<b>Air Releases</b>
Releases are possible but cannot be quantified (Not quantifiable).
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
Releases are possible but cannot be quantified (Not quantifiable).
<b>Products</b>
None.

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**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<sub>98</sub> TEQ<sub>DF</sub>/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**

1 No information was found indicating that CDD/CDFs were present in water releases from  
2 these facilities.

3

4 **7.8.3. Solid Residue Releases**

5 Sludges and ashes are stored in collection pits at these facilities. No information was  
6 found indicating that CDD/CDFs were present in solid residues from these facilities. However,  
7 it is reasonable to assume that CDD/CDFs are present in these ashes because they have been  
8 found in the ash from other types of combustion. Lacking measurement information, no  
9 estimates of releases from solid residues can be made (Not quantifiable). The portion of the  
10 solid waste that is disposed in landfills would not be considered an environmental release.

11

12 **7.8.4. Products**

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

15

16 **7.8.5. Release Summary**

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

18

<b>Inventory Decision Criteria for Drum and Barrel Reclamation Furnaces</b>	
	<b>Air Water Solids Products</b>
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

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<b>Drum and Barrel Reclamation Furnaces</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"><li>• 1987—17.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/drum (16.5 ng I-TEQ<sub>DF</sub>/drum) (Preliminary).</li><li>• 1995—17.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/drum (16.5 ng I-TEQ<sub>DF</sub>/drum) (Preliminary).</li><li>• 2000—17.5 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/drum (16.5 ng I-TEQ<sub>DF</sub>/drum) (Preliminary).</li></ul>
<b>Activity Levels</b> <ul style="list-style-type: none"><li>• 1987—35 million drums burned.</li><li>• 1995—35 million drums burned.</li><li>• 2000—35 million drums burned.</li></ul>
<b>Releases</b> <ul style="list-style-type: none"><li>• 1987—0.6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.6 g I-TEQ<sub>DF</sub>) (Preliminary).</li><li>• 1995—0.6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.6 g I-TEQ<sub>DF</sub>) (Preliminary).</li><li>• 2000—0.6 g WHO<sub>98</sub> TEQ<sub>DF</sub> (0.6 g I-TEQ<sub>DF</sub>) (Preliminary).</li></ul>
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
Releases are possible but cannot be quantified.
<b>Products</b>
None.

3

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1                   **8. CHEMICAL MANUFACTURING AND PROCESSING SOURCES**

2  
3  
4           **8.1. BLEACHED CHEMICAL WOOD PULP AND PAPER MILLS**

5           No changes were made to the release estimates for these facilities; however, some  
6 additional discussion is provided below to clarify how the estimates were derived.

7  
8           **8.1.1. Air Releases**

9           Air releases from incineration of sludges are covered in Section 3.7.

10  
11           **8.1.2. Water Releases**

12           For 1987 and 1995, an emission-factor approach was not needed because release  
13 estimates were available for virtually all facilities. These data came from six industry-wide  
14 surveys as described in EPA (2006).

15           An emission-factor approach was used to estimate releases in 2000 because a  
16 comprehensive plant survey was not done for this year. The emission factor and activity  
17 estimates were provided by NCASI (Gillespie, 2002) based on data from multiple facilities.

18  
19           **8.1.3. Solid Residue Releases**

20           As described in EPA (2006), the amounts of CDD/CDFs in solid residues came from the  
21 comprehensive industry surveys in 1987 and 1995. In 1990, the majority (75.5%) of the  
22 wastewater sludge generated by these facilities was placed in landfills or in surface  
23 impoundments, with the remainder incinerated (20.5%), applied to land or used as compost  
24 (4.1%), or distributed as a commercial product (less than 1%) (U.S. EPA, 1993b). Data on the  
25 disposition of wastewater sludges are available only for years 1988 through 1995. On the basis  
26 of these data, the best estimate of the amount applied to land (i.e., not incinerated or landfilled) is  
27 14.1 g WHO<sub>98</sub> or I-TEQ (4.1% of 343 g) for 1987 and 2 g 1 g WHO<sub>98</sub> or I-TEQ (4.1% of 50 g)  
28 for 1995.

29           For 2000, the primary waste treatment residuals from pulp mills  
30 (0.974 million dry MT/year) and the combined, secondary, and dredged waste treatment  
31 residuals from pulp mills (1.37 million dry MT/year) were derived from the NCASI database  
32 (Gillespie, 2002) on multiple facilities. This yields a total sludge production of

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1 2.34 million dry MT. Fifty-one percent of the sludge generated in 2000 was sent to landfills or  
2 lagoons (Gillepsie, 2002). It is uncertain how much of the remaining 49% of the sludge was  
3 applied to land. However, a conservative estimate can be developed by applying the 4.1% used  
4 to develop the 1987 and 1995 estimates. This implies that 1.19 MMT was landfilled and  
5 0.096 MMT were land applied.

6 The CDD/CDFs in sludges that are land applied are assumed to represent environmental  
7 releases. These amounts are shown in the release summary below. The CDD/CDFs in sludges  
8 that are landfilled are not considered to be environmental releases, and these amounts are listed  
9 below:

10

- 11 • 1987—260 g WHO<sub>98</sub> or I-TEQ/year
- 12 • 1995—38 g WHO<sub>98</sub> or I-TEQ/year
- 13 • 2000—2 g WHO<sub>98</sub> or I-TEQ/year

14

#### 15 **8.1.4. Products**

16 The surveys discussed above provide information on the amounts of CDD/CDFs found in  
17 wood pulp: 500 g WHO<sub>98</sub> or I-TEQ in 1987, 40 g WHO<sub>98</sub> or I-TEQ in 1995, and 0.6 g WHO<sub>98</sub> or  
18 I-TEQ in 2000. It is unknown if environmental releases occur from paper products made from  
19 the pulp. The CDD/CDFs in wood pulp products can be considered to be a reservoir as  
20 discussed further in Chapter 11.

21

#### 22 **8.1.5. Release Summary**

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

<b>Inventory Decision Criteria for Bleached Chemical Wood Pulp and Paper Mills</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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	

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<b>Bleached Chemical Wood Pulp and Paper Mills</b>	
<b>Air Releases</b>	
Air releases from incineration of sludges are covered in Section 3.7.	
<b>Water Releases</b>	
<b>Emission Factor</b>	
<ul style="list-style-type: none"> <li>• 2000—0.49 pg (WHO<sub>98</sub> or I-TEQ/L) of wastewater.</li> </ul>	
<b>Activity Level</b>	
<ul style="list-style-type: none"> <li>• 2000—2.87 trillion L.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—360 g (WHO<sub>98</sub> or I-TEQ).</li> <li>• 1995—28 g (WHO<sub>98</sub> or I-TEQ).</li> <li>• 2000—1 g (WHO<sub>98</sub> or I-TEQ).</li> </ul>	
<b>Solid Residue Releases</b>	
<b>Emission Factor</b>	
<ul style="list-style-type: none"> <li>• 2000—1.8 ng (WHO<sub>98</sub> or I-TEQ/kg) of sludge.</li> </ul>	
<b>Activity Level</b>	
<i>Land Applied</i>	
<ul style="list-style-type: none"> <li>• 2000—0.096 million dry MT.</li> </ul>	
<b>Releases</b>	
<i>Land Applied</i>	
<ul style="list-style-type: none"> <li>• 1987—14 g (WHO<sub>98</sub> or I-TEQ).</li> <li>• 1995—2 g (WHO<sub>98</sub> or I-TEQ).</li> <li>• 2000—0.2 g (WHO<sub>98</sub> or I-TEQ).</li> </ul>	
<b>Products</b>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not quantifiable.</li> <li>• 1995—Not quantifiable.</li> <li>• 2000—Not quantifiable.</li> </ul>	

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## 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

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1 8.3—Stand-Alone Vinyl Chloride Manufacturing Plants

2 8.4—Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics

3  
4 Because the changes to these sections are extensive, they are presented here in their entirety.  
5 Although the reorganization is extensive, only minor changes were made to the release estimates.

6 This section covers plants that produce only chlorine, sodium hydroxide (NaOH), and  
7 related caustic chemicals (also known as chlor-alkali plants). These chemicals are also produced  
8 at complex plants that produce a variety of chlorinated organic compounds. The CDD/CDF  
9 releases associated with chlor-alkali production at these complex plants are covered in  
10 Section 8.4.

11  
12 **8.2.1. Process Description**

13 Chlorine gas is produced by electrolysis of brine in electrolytic cells. Three processes are  
14 in use: the diaphragm-cell process, the membrane-cell process, and the mercury-cell process. In  
15 the diaphragm-cell process, a porous diaphragm divides the electrolytic cell, which contains  
16 brine, into an anode compartment and a cathode compartment. When an electric current passes  
17 through the brine, the chlorine ions and sodium ions from the salt move to the electrodes.  
18 Chlorine gas is produced at the anode, and sodium ions at the cathode react with the water,  
19 forming caustic soda. In the membrane-cell process, the compartments are separated by a  
20 membrane rather than a diaphragm. Brine is pumped into the anode compartment, and only  
21 sodium ions pass into the cathode compartment, which contains pure water. Thus, the caustic  
22 soda produced has very little salt contamination. In the mercury-cell process, mercury, which  
23 flows along the bottom of the electrolytic cell, serves as the cathode. When an electric current  
24 passes through the brine, chlorine is produced at the anode, and sodium dissolves in the mercury,  
25 forming an amalgam of sodium and mercury (Chlorine Institute, 2010).

26 Until the late 1970s, the primary type of electrolytic process used in the chlor-alkali  
27 industry to produce chlorine consisted of the use of mercury cells containing graphite electrodes.  
28 During the 1980s, titanium metal anodes were developed to replace graphite electrodes  
29 (U.S. EPA, 1982; Curlin and Bommaraju, 1991). Currently, no U.S. facility is believed to use  
30 graphite electrodes in the production of chlorine gas (telephone conversation between L. Phillips,  
31 Versar, Inc., and T. Fielding, U.S. EPA, Office of Water, February 1993).

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1 **8.2.2. Regulations**

2 Although EPA does not regulate CDDs/CDFs specifically, it issued restrictions under  
3 RCRA on the land disposal of wastewater and sludges generated by chlorine manufacturers that  
4 use the mercury-cell process and the diaphragm-cell process (with graphite electrodes) (waste  
5 codes K071, K073, and K106) (40 CFR 268).

6  
7 **8.2.3. Literature**

8 As shown in Table 8-1, high levels of CDFs have been found in several samples of  
9 graphite electrode sludge from facilities in Europe. The CDFs predominate in these sludges, and  
10 the 2,3,7,8-substituted congeners account for a large fraction of the respective congener totals  
11 (Rappe et al., 1990, 1991; Rappe, 1993; Strandell et al., 1994). Although the origin of the CDFs  
12 in graphite electrode sludge is uncertain, chlorination of the cyclic aromatic hydrocarbons (such  
13 as dibenzofuran) present in the coal tar used as a binding agent in the graphite electrodes has  
14 been proposed as the primary source (Strandell et al., 1994). For this reason, sludges produced  
15 using metal electrodes were not expected to contain CDFs. However, results of an analysis of  
16 metal electrode sludge from a facility in Sweden, analyzed as part of the Swedish Dioxin Survey,  
17 showed that the sludge contained high levels of CDFs (similar to those of the graphite sludge)  
18 and primarily nondetectable levels of CDDs (Strandell et al., 1994). The sludge showed the  
19 same type of CDF congener pattern reported by Rappe et al. (1991) and Rappe (1993). Strandell  
20 et al. suggested that chlorination of polyaromatic hydrocarbons present in the rubber linings of  
21 the electrolytic cell may have produced the CDFs found in the one sample analyzed.

22 The Chlorine Chemistry Council (CCC), a trade association representing manufacturers  
23 that produce and/or use chlorine, sampled a variety of waste streams at seven stand-alone  
24 chlor-alkali facilities in the United States (CCC, 2004). Note that one of these plants (Occidental  
25 in Deer Park, TX) also produced vinyl chloride monomer (VCM), but the processes and  
26 associated waste streams are adequately separated such that it can be treated as a stand-alone  
27 facility. This information is also summarized in Dyke and Amendola (2007). This study  
28 measured CDD/CDF releases to water from all seven facilities as summarized in Table 8-2. Air  
29 releases were only detected at one facility (see Table 8-3). Dyke and Amendola (2007)  
30 summarized the amount of CDD/CDF in all waste streams and provided a confidence rating for  
31

1 each value (see Table 8-4). Table 8-4 shows the amount of CDD/CDFs that are sent to off-site  
2 incinerators, landfills, and deep-well injection facilities. The releases from incineration are  
3 included in the estimates presented for hazardous waste incinerators (see Section 3.2). The  
4 amounts sent to secure landfills and deep-well injection facilities are not considered to be  
5 environmental releases.

6 Dyke and Amendola (2007) present release estimates for both the years 2000 and 2002.  
7 The 2002 values are not reproduced here but are generally lower or similar to the 2000 values.

8 In the year 2000, five facilities with an SIC code for alkalies and chlorine reported dioxin  
9 releases under the EPA TRI program (U.S. EPA, 2008). The sum of the air releases across these  
10 facilities was 204 g, which EPA estimates is equal to 3.3 g WHO<sub>98</sub> TEQ<sub>DF</sub>. The sum of the  
11 water releases across these facilities was 1,416 g, which EPA estimates is equal to  
12 24.8 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were reported. As explained in Chapter 1, the  
13 TRI data are not used to make quantitative estimates in this document but rather as supportive  
14 evidence that releases do occur.

#### 16 **8.2.4. Releases**

17 The information presented in Dyke and Amendola (2007) was selected as the best basis  
18 for estimating CDD/CDF releases from these facilities. The seven stand-alone chlor-alkali plants  
19 covered in this study are believed to represent most of the stand-alone chlor-alkali production in  
20 the United States. Therefore, it was unnecessary to develop emission factors to estimate releases  
21 from untested facilities. The Dyke and Amendola release estimates are specific to the year 2000.  
22 No release data were found for earlier years. Because the chemical production rates and  
23 technologies used at these facilities were probably similar in 1995 and 2000, the 2000 results are  
24 assumed to apply to 1995. However, significant changes may have occurred since 1987, so no  
25 release estimates could be made for 1987. The releases to all media are presented in Table 8-4  
26 and summarized below.

27 The solid residues from these plants are disposed in secure landfills or by deep-well  
28 injection and, therefore, are not considered an environmental release. The amounts are  
29 summarized below:

- 30 • 1987—Not Available

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- 1 • 1995—2.7 g I-TEQ
- 2 • 2000—2.7 g I-TEQ

3  
4 The inventory decision criteria and releases to all media are summarized below:

<b>Inventory Decision Criteria for Stand-Alone Chlor-Alkali Plants</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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		

<b>Stand-Alone Chlor-Alkali Plants</b>	
<b>Air Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—0.03 g I-TEQ.</li> <li>• 2000—0.03 g I-TEQ.</li> </ul>	
<b>Water Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—2 g I-TEQ.</li> <li>• 2000—2 g I-TEQ.</li> </ul>	
<b>Solid Residue Releases</b>	
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.	
<b>Products</b>	
No information was found suggesting that CDD/CDFs are found in the products from these facilities.	

8  
9  
10 **8.3. STAND-ALONE VINYL CHLORIDE MANUFACTURING PLANTS**

11  
12 *This document is a draft for review purposes only and does not constitute Agency policy.*

1 As explained at the beginning of Section 8.2, this is a new section based on the  
2 reorganization of Sections 8.2 and 8.3 in the original report. This section covers plants that  
3 produce only polyvinyl chloride (PVC) and PVC intermediates such as ethylene dichloride  
4 (EDC) and VCM. These chemicals are also produced at complex plants that produce a variety of  
5 chlorinated organic compounds. The CDD/CDF releases associated with vinyl chloride  
6 production at these complex plants are covered in Section 8.4.

### 7 8 **8.3.1. Process**

9 PVC resins are produced from the polymerization of VCM. VCM is typically produced  
10 by the thermal dehydrochlorination (commonly known as cracking) of EDC. The cracking of  
11 EDC requires elevated pressure (20 to 30 atm) and temperature (450 to 650EC) and yields VCM  
12 and HCl at about a 1:1 molar ratio. EDC is produced by two different methods: (1) direct  
13 chlorination of ethylene with chlorine in the presence of a catalyst at a temperature of 50 to  
14 60EC and pressure of 4 to 5 atm; and (2) oxychlorination, which involves reaction of ethylene  
15 with HCl and oxygen in the presence of a catalyst at temperatures generally less than 325EC.  
16 The primary source of HCl for the oxychlorination process is the HCl produced from the  
17 cracking of EDC to form VCM. Most VCM manufacturing facilities are integrated with EDC  
18 production facilities (The Vinyl Institute, 1998).

### 19 20 **8.3.2. Regulations**

21 Although EPA regulates emissions from EDC/VCM production facilities under the Clean  
22 Water Act (40 CFR 61), the Clean Air Act (40 CFR 414), and RCRA (40 CFR 268, waste codes  
23 F024, K019, and K020), CDDs/CDFs are not specifically regulated pollutants.

### 24 25 **8.3.3. Literature**

26 Although it has been generally recognized that CDDs/CDFs can be formed during the  
27 manufacture of EDC, VCM, and PVC, manufacturers and environmental public interest groups  
28 have disagreed as to the quantity of CDDs/CDFs that are formed and released to the environment  
29 in wastes and possibly in PVC products. Greenpeace International initially determined that  
30 CDDs and CDFs can be formed during the manufacture of PVC. In 1993, it issued a report on  
31 CDD/CDF emissions associated with the production of EDC/VCM (Greenpeace, 1993).

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1 Greenpeace estimated that 5 to 10 g I-TEQ<sub>DF</sub> were released to the environment (air, water, and  
2 ground combined) annually for every 100,000 MT of VCM produced. This emission factor was  
3 based on data gathered by Greenpeace on four European plants. The Vinyl Institute responded  
4 with a critique of the Greenpeace report (ChemRisk, 1993). Miller (1993) summarized the  
5 differing views of the two parties. According to Miller, European PVC manufacturers claimed  
6 the emission factor was 0.01 to 0.5 g I-TEQ<sub>DF</sub>/100,000 MT of VCM, and although Greenpeace  
7 and ChemRisk used basically the same monitoring information to develop their emission factors,  
8 Greenpeace adjusted the emission factor to account for unquantified fugitive emissions and  
9 waste products that contain unspecified amounts of CDDs/CDFs.

10 In 1995, Greenpeace issued a second report (Stringer et al., 1995) reiterating the  
11 organization's concern that the generation and the emission of CDDs/CDFs may be significant  
12 and urging that further work be initiated to quantify and prevent emissions. Stringer et al. (1995)  
13 presented the results of analyses of three samples of chlorinated wastes obtained from  
14 U.S. EDC/VCM manufacturing facilities. The three samples were characterized according to  
15 EPA hazardous waste classification numbers as an F024 waste (waste from the production of  
16 short-chain aliphatics by free radical-catalyzed processes), a K019 waste (heavy ends from the  
17 distillation of ethylene from EDC production), and a probable K020 waste (heavy ends from  
18 distillation of vinyl chloride in VCM manufacturing). Table 8-5 presents the analytical results  
19 reported by Stringer et al. (1995). This study acknowledged that because EDC/VCM production  
20 technologies and waste treatment and disposal practices are very site-specific, the limited  
21 information available on CDD/CDF generation and emissions made it difficult to quantify  
22 amounts of CDDs/CDFs generated and emitted.

23 In response to the lack of definitive studies, and at the recommendation of the EPA,  
24 U.S. PVC manufacturers began an extensive monitoring program—the Dioxin Characterization  
25 Program (DCP). The objective of the DCP was to evaluate the extent and magnitude of potential  
26 CDD/CDF releases to air, water, and land, as well as the potential for PVC product  
27 contamination. Manufacturers performed emissions and product testing at several facilities that  
28 were representative of various manufacturing and process control technologies. In 1998, The  
29 Vinyl Institute completed studies of CDD/CDF releases in wastewater, wastewater treatment  
30 plant solids, and stack gases, as well as studies of the CDD/CDF content of products (PVC resins  
31 and EDC sold as products) (The Vinyl Institute, 1998). This study presented results for

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1 22 samples from 14 of the 24 U.S. and Canadian facilities manufacturing suspension and mass  
2 PVC resins (13 pipe resins, 3 bottle resins, and 6 packaging resins). The results for U.S.  
3 manufacturers are summarized in Table 8-6. The 14 sampled sites represented approximately  
4 74% of estimated 1995 U.S. and Canadian suspension and mass PVC resin production.  
5 CDDs/CDFs were detected in only one sample (0.043 ng I-TEQ<sub>DF</sub>/kg, assuming nondetects  
6 equal to zero). The overall mean TEQ concentrations were 0.002 ng I-TEQ<sub>DF</sub>/kg (assuming  
7 nondetects equal to zero) and 0.7 ng I-TEQ<sub>DF</sub>/kg (assuming nondetects equal to one-half the  
8 DL). The DLs were 2 ng/kg or less for all congeners in all samples except for OCDD and  
9 OCDF, which had DLs of 6 ng/kg or less.

10 The same study also presented results for six samples from four of the seven U.S.  
11 facilities manufacturing dispersion PVC resins. CDDs/CDFs were detected in five of the  
12 samples. The results are summarized in Table 8-6. In terms of production, the four sampled  
13 sites represent approximately 61% of estimated 1995 U.S. dispersion PVC resin production. The  
14 results ranged from not detected to 0.008 ng I-TEQ<sub>DF</sub>/kg (overall mean = 0.001 ng I-TEQ<sub>DF</sub>/kg,  
15 assuming nondetects equal to zero, and 0.4 ng I-TEQ<sub>DF</sub>/kg, assuming nondetects equal to  
16 one-half the DL). The DLs were 2 ng/kg or less for all congeners in all samples except for  
17 OCDD and OCDF, which had DLs of 4 ng/kg or less.

18 Results were also presented for five samples from 5 of the 15 U.S. facilities  
19 manufacturing EDC. The results are summarized in Table 8-6. In terms of production, the  
20 five sampled sites represented approximately 71% of the estimated EDC produced in the United  
21 States in 1995. CDDs/CDFs were detected in only one sample (0.03 ng I-TEQ<sub>DF</sub>/kg). The  
22 overall mean TEQ concentrations were 0.006 ng I-TEQ<sub>DF</sub>/kg (nondetects equal to zero) and  
23 0.21 ng I-TEQ<sub>DF</sub>/kg (nondetects equal to one-half the DL). The DLs for all congeners were  
24 1 ng/kg or less.

25 EPA (2006) used concentration and production data to estimate that vinyl chloride  
26 contained 0.02 g I-TEQ in 1995 and 0.02 g I-TEQ in 2000. It is unknown if releases occurred  
27 from these products.

28 The Chlorine Chemistry Council (CCC), a trade association representing manufacturers  
29 that produce and/or use chlorine, also sponsored studies to measure CDD/CDF releases from the  
30 production of chlorine and chlorinated organics. The information from The Vinyl Institute and  
31 CCC studies was summarized in a recent article by Dyke and Amendola (2007). This article

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1 identifies two facilities as stand-alone vinyl chloride plants. Dyke and Amendola (2007)  
2 summarized the releases of CDD/CDF to all media for the year 2000 and provided a confidence  
3 rating for each value analogous to one used in this report (see Table 8-7). Dyke and Amendola  
4 (2007) presented release estimates for both the years 2000 and 2002. The 2002 values are not  
5 reproduced here but are generally lower or similar to the 2000 values.

6

#### 7 **8.3.4. Releases**

8 The information presented in Dyke and Amendola (2007) was selected as the best basis  
9 for estimating CDD/CDF releases from these facilities. The two stand-alone vinyl chloride  
10 plants covered in this study are believed to represent most of the stand-alone vinyl chloride  
11 production in the United States. Therefore, it was not necessary to develop emission factors to  
12 estimate releases from untested facilities. The Dyke and Amendola (2007) release estimates are  
13 specific to the year 2000. Since the chemical production rates and technologies used at these  
14 facilities have changed significantly since 1987, release estimates cannot be made for 1987 and  
15 1995.

16 Table 8-7 shows the amount of CDD/CDFs that are sent to off-site incinerators and  
17 landfills. The releases from incineration are included in the estimates presented for hazardous  
18 waste incinerators (see Section 3.2). The amount sent to secure landfills (5.57 g I-TEQ in 2000)  
19 is not considered to be an environmental release.

20 As discussed above, several studies have detected CDD/CDFs in PVC products.  
21 However, no information is available on possible releases from these products, and therefore,  
22 they are a potential but unquantifiable source (Not quantifiable).

23 The releases to all media from the stand-alone vinyl chloride plants are presented in  
24 Table 8-7.

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

26

<b>Inventory Decision Criteria for Stand-Alone Vinyl Chloride Manufacturing Plants</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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		

1  
2

<b>Stand-Alone Vinyl Chloride Manufacturing Plants</b>	
<b>Air Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—Not available.</li> <li>• 2000—0.62 g I-TEQ.</li> </ul>	
<b>Water Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—Not available.</li> <li>• 2000—&lt;0.1 g I-TEQ.</li> </ul>	
<b>Solid Residue Releases</b>	
None. The solid residues from these plants are disposed in secure landfills and, therefore, are not considered to be an environmental release.	
<b>Products</b>	
Not quantifiable.	

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#### **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.

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1 The waste streams at these complex plants are typically combined, which prevents  
2 derivation of chemical-specific release estimates. Instead, a facility-specific approach has been  
3 used where the releases for each plant are estimated on the basis of the CDD/CDF levels and  
4 total flow rates measured at the final release point.

5 These plants currently—or have in the past—produced a variety of chemicals that have  
6 been associated with CDD/CDF releases. These include chlorine, vinyl chloride, chlorophenols,  
7 chlorobenzenes, and chlorobiphenyls. Background information on the regulations, processes,  
8 and products related to chlorine and vinyl chloride products were presented in Sections 8.2 and  
9 8.3, respectively. Therefore, they are not repeated in this section. The production and use of  
10 chlorophenols, chlorophenoxy herbicides, and PCB products are now banned or strictly regulated  
11 in most countries. PCB production ceased prior to the first reference year, i.e., 1987. So  
12 CDD/CDF releases associated with PCB production are not covered in this report (PCB releases  
13 from nonproduction contemporary sources are covered in Chapter 10, and releases from  
14 reservoirs are covered in Chapter 11).

15 Section 8.4 first presents separate discussions on chlorophenol and chlorobenzenes.  
16 These discussions describe the manufacturing processes, regulations, and products for these  
17 chemical groups. Then the section presents the release estimates occurring during production  
18 activities at the complex plants.

## 19

### 20 **8.4.1. Chlorophenols**

#### 21 **8.4.1.1. Process Description**

22 The two major commercial methods used to produce chlorophenols are (1) electrophilic  
23 chlorination of molten phenol by chlorine gas in the presence of catalytic amounts of a metal  
24 chloride and organic chlorination promoters and stabilizers, and (2) alkaline hydrolysis of  
25 chlorobenzenes under heat and pressure using aqueous methanolic sodium hydroxide. Other  
26 manufacturing methods include conversion of diazonium salts of various chlorinated anilines and  
27 chlorination of phenolsulfonic acids and benzenesulfonic acids, followed by the removal of the  
28 sulfonic acid group (Gilman et al., 1988; Hutzinger and Fiedler, 1991b).

1 **8.4.1.2. Regulations for Chlorophenols**

2 In 1983, EPA cancelled the sale of Silvex and 2,4,5-T for all uses (Federal Register,  
3 1987a). Earlier, in 1979, EPA had ordered emergency suspension of the forestry, rights-of-way,  
4 and pasture uses of 2,4,5-T. Emergency suspensions of the forestry, rights-of-way, pasture,  
5 home and garden, commercial/ornamental turf, and aquatic weed control/ditch bank uses of  
6 Silvex were also ordered (Federal Register, 1979; Plimmer, 1980). The home and garden,  
7 commercial/ornamental turf, and aquatic weed control/ditch bank uses of 2,4,5-T had been  
8 suspended in 1970.

9 Pentachlorophenol (PCP) was one of the most widely used biocides in the United States  
10 prior to the regulatory actions to cancel and restrict certain of its wood and nonwood preservative  
11 uses. PCP was registered for use as a herbicide, defoliant, mossicide, and mushroom house  
12 biocide. It also found use as a biocide in pulp-paper mills, oil wells, and cooling towers. These  
13 latter three uses were terminated on or before 1993 (U.S. EPA, 1993b). However, the major use  
14 (greater than 80% of consumption) of PCP was and continues to be wood preservation. An  
15 overview of the history of the PCP pesticide rules is presented below.

16 In 1984, EPA issued a notice of intent to cancel registrations of pesticide products  
17 containing PCP (including its salts) for all wood preservative uses (Federal Register, 1984). This  
18 notice specified modifications to the terms and conditions of product registrations that were  
19 required in order to avoid cancellation of the products. In response to this notice, several trade  
20 associations and registrants requested administrative hearings to challenge EPA's  
21 determinations. After considering the comments and alternatives suggested during the  
22 prehearing stage of the administrative proceedings, EPA concluded that certain changes to the  
23 1984 notice were appropriate. These changes, finalized in 1986 (Federal Register, 1986),  
24 included the following: (a) all wood preservative uses of PCP and its salts were classified as  
25 "restricted use" only by certified applicators, (b) specific worker protection measures were  
26 required, (c) limits were placed on the HxCDD content of PCP, and (d) label restrictions for  
27 home and farm uses of PCP prohibited its application indoors and to wood intended for interior  
28 use (with a few exceptions) as well as its application in a manner that might result in direct  
29 exposure of domestic animals or livestock or in the contamination of food, feed, or drinking and  
30 irrigation water.

1 EPA subsequently amended its notice on the wood preservative uses to establish reliable  
2 and enforceable methods for implementing certified limits for HxCDD and 2,3,7,8-TCDD in  
3 registered wood preservative pesticide products (Federal Register, 1987b). Levels of  
4 2,3,7,8-TCDD were not allowed to exceed 1 ppb in any product, and after February 2, 1989, any  
5 manufacturing-use PCP released for shipment could not contain HxCDD levels that exceeded an  
6 average of 2 ppm over a monthly release or a batch level of 4 ppm (a gradually phased-in  
7 requirement). On January 21, 1987, EPA prohibited the registration of PCP and its salts for most  
8 nonwood uses (Federal Register, 1987c). EPA deferred action on several uses (uses in  
9 pulp/paper mills, oil wells, and cooling towers) pending receipt of additional exposure, use, and  
10 ecological effects data. On January 8, 1993, EPA issued a press advisory stating that its special  
11 review of these deferred nonwood uses was being terminated because all of these uses had been  
12 either voluntarily cancelled by the registrants or cancelled by EPA for failure of the registrants to  
13 pay the required annual maintenance fees (U.S. EPA, 1993b).

14 Di- and trichlorophenol manufacturers are subject to reporting under the Dioxin/Furan  
15 Test Rule, which is discussed in Section 8.3.7 of the original report. Since the effective date of  
16 that rule (June 5, 1987), only the 2,4-dichlorophenol isomer has been commercially produced in  
17 (or imported to) the United States, and as noted in Table 8-8, no CDDs/CDFs were detected in  
18 the product. Testing is required for the other di- and trichlorophenols if manufacture or  
19 importation resumes. Similarly, tetrachlorophenols were subject to reporting under the  
20 Dioxin/Furan Pesticide Data Call-In (discussed in Section 8.3.8 of the original report). Since  
21 issuance of the Data Call-in, the registrants of tetrachlorophenol-containing pesticide products  
22 have elected to no longer support the registration of their products in the United States.

23 In the mid-1980s, the EPA Office of Solid Waste (OSW) promulgated, under RCRA,  
24 land disposal restrictions on wastes (wastewaters and nonwastewaters) resulting from the  
25 manufacture of chlorophenols (40 CFR 268). Table 8-9 lists all wastes in which CDDs/CDFs are  
26 specifically regulated by EPA as hazardous constituents, including chlorophenol wastes (waste  
27 codes F020 and F021). The regulations prohibit the land disposal of these wastes until they are  
28 treated to a level below the routinely achievable DLs for the EPA hazardous waste numbers  
29 listed in Table 8-9 for each of the following congener groups: TCDDs, PeCDDs, HxCDDs,  
30 TCDFs, PeCDFs, and HxCDFs. Wastes from PCP-based wood-preserving operations (waste  
31 codes K001 and F032) are also regulated as hazardous wastes under RCRA (40 CFR 261).

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1 The EPA Office of Water promulgated effluent limitations for facilities that manufacture  
2 chlorinated phenols and discharge treated wastewater (40 CFR 414.70). These effluent  
3 limitations do not specifically regulate CDDs or CDFs. The effluent limitations for the  
4 individually regulated chlorinated phenols are less than or equal to 39 µg/L for facilities that use  
5 biological end-of-pipe treatment.

### 7 **8.4.1.3. Products—Chlorophenols**

8 Chlorophenols have been widely used for a variety of pesticidal applications. The  
9 higher-chlorinated phenols (tetrachlorophenol and PCP) and their sodium salts have been used  
10 primarily for wood preservation. The lower-chlorinated phenols have been used primarily as  
11 chemical intermediates in the manufacture of other pesticides. For example, 2,4-dichlorophenol  
12 is used to produce the herbicides 2,4-dichlorophenoxyacetic acid (2,4-D),  
13 4-(2,4-dichlorophenoxy)butanoic acid (2,4-DB), 2-(2,4-dichlorophenoxy)-propanoic acid  
14 (2,4-DP), Nitrophen, Genite, and Zytron, and 2,4,5-trichlorophenol was used to produce  
15 hexachlorophene, 2,4,5-T, Silvex, Erbon, Ronnel, and Gardona (Gilman et al., 1988; Hutzinger  
16 and Fiedler, 1991b).

17 Because of the manufacturing processes employed, commercial chlorophenol products  
18 can contain appreciable amounts of impurities (Gilman et al., 1988). During the direct  
19 chlorination of phenol, CDDs/CDFs can form either by the condensation of tri-, tetra-, and  
20 pentachlorophenols or by the condensation of chlorophenols with hexachlorocyclohexadienone  
21 (which forms from excessive chlorination of phenol). During alkaline hydrolysis of  
22 chlorobenzenes, CDDs/CDFs can form through chlorophenate condensation (Ree et al., 1988;  
23 Gilman et al., 1988; Hutzinger and Fiedler, 1991b)

24 The limited information on CDD/CDF concentrations in chlorophenols published in the  
25 1970s and early 1980s was compiled by Versar, Inc. (1985) and Hutzinger and Fiedler (1991b).  
26 The results of several major studies cited by these reviewers (Firestone et al., 1972; Rappe and  
27 Marklund, 1978; Rappe et al., 1978) are presented in Table 8-8. Typically, CDDs/CDFs were  
28 not detected in mono- and dichlorophenols but were reported in tri- and tetrachlorophenols.  
29 More recent results of testing of 2,4-dichlorophenol, performed in response to the Toxic  
30 Substances Control Act (TSCA) dioxin/furan test rule, showed no detectable concentrations of  
31 2,3,7,8-substituted tetra- through hepta-CDD/CDFs.

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1 Detailed information on 2,4,5-T production and 2,3,7,8-TCDD levels was presented in  
2 Chapter 11 of the original report. Production of 2,4,5-T during the 1950s, 1960s, and 1970s was  
3 estimated as 2,000, 4,000, and 1,500 MT/year, respectively. This was combined with estimates  
4 of 2,3,7,8-TCDD levels in the product to estimate that the cumulative amount of 2,3,7,8-TCDD  
5 in 2,4,5-T used over the period of 1950 to 1979 was 36,000 g. No product release estimates are  
6 presented for the reference years because production ceased prior to 1987. After the chemical  
7 was applied, it would have become incorporated into the soil reservoir. The potential amounts of  
8 2,3,7,8-TCDD remaining in the soil reservoir and possible releases are discussed in Chapter 11.

9 The production of PCP for wood preserving began on an experimental basis in the 1930s.  
10 In 1947, nearly 3,200 MT of PCP were reported to have been used in the United States by the  
11 commercial wood preserving industry. Use in this industry steadily increased through the  
12 mid-1970s (AWPI, 1977). Although domestic consumption volumes are not available for all  
13 years, it is estimated, on the basis of historical production/export data for PCP reported in  
14 Mannsville (1983), that 90 to 95% of production volume has typically been consumed  
15 domestically rather than exported. A reasonable estimate of total domestic PCP consumption  
16 during the period of 1970 to 1995 is about 400,000 MT. This estimate assumes an average  
17 annual consumption rate of 20,000 MT/year during the 1970s, 15,000 MT/year during the 1980s,  
18 and 10,000 MT/year during the 1990s.

19 Table 8-10 presents a compilation of published data on the CDD/CDF content of  
20 technical-grade PCP. The only samples that have been analyzed for all dioxin-like CDDs/CDFs  
21 were manufactured in the mid-to-late 1980s. Figure 8-1 presents these data in graphical form. It  
22 shows that the predominant congener groups are OCDD, OCDF, and HpCDD, Waddell et al.  
23 (1995) tested analytical-grade PCP (from Aldrich Chemical Co.) for CDD/CDF content and  
24 found the same congener profile; however, the CDD/CDF levels were three to four orders of  
25 magnitude lower. Table 8-11 presents a similar compilation of published data on the CDD/CDF  
26 content of PCP-Na. The table shows the same patterns of dominant congeners and congener  
27 groups reported for PCP

28 Samples of technical-grade PCP manufactured during the mid-to-late 1980s contained  
29 about 1.7 mg WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (3 mg I-TEQ/kg), based on the data presented in Table 8-10.  
30 No published reports could be located that present the results of any congener-specific analyses  
31 of PCP manufactured since the late 1980s. However, monthly measurements of CDD/CDF

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1 congener group concentrations in technical PCP manufactured for use in the United States have  
2 been reported to EPA from 1987 to the present (letter dated March 5, 1997, from Thomas  
3 Mitchell, KMG-Bernuth, to Matthew Lorber, U.S. EPA; letter dated February 7, 1997, from John  
4 Wilkinson, Pentachlorophenol Task Force, to Matthew Lorber, U.S. EPA; U.S. EPA, 1999a).  
5 The average congener group concentrations reported to EPA for the years 1988 (i.e., 1 year after  
6 EPA regulations were imposed limiting HxCDD and 2,3,7,8-TCDD concentrations in PCP) to  
7 1999 are presented in Table 8-10. In general, the average congener group concentrations during  
8 the period of 1988 to 1999 are lower by a factor of 2 to 4 than the concentrations observed in the  
9 mid-to-late 1980 (based on the full-congener analysis of samples). If it is assumed that the toxic  
10 CDD/CDF congeners have also been reduced by a similar factor, then the TEQ content of PCP  
11 manufactured since 1988 is about 0.6 mg WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (1 mg I-TEQ/kg).

12 An estimated 12,000 MT of PCP were used for wood preservation in the United States in  
13 1987 (WHO, 1991). An estimated 8,400 MT were used in 1994 (AWPI, 1995); for the purposes  
14 of this report, it is assumed that an identical amount was used in 1995. In 1999, approximately  
15 7,710 MT of PCP were produced annually in the United States (Council of Great Lakes  
16 Industries, 1999); for the purposes of this report, it is assumed that an identical amount was  
17 produced in 2000. Assuming that 95% of the production volume was consumed domestically  
18 (Mannsville, 1983) and that all of the PCP produced in 2000 was used for wood preservation,  
19 approximately 7,325 MT of PCP were used in the United States for wood preservation.

20 Combining these activity level estimates with the TEQ concentration estimates presented above  
21 indicates that 20,000 g WHO<sub>98</sub> TEQ<sub>DF</sub> (36,000 g I-TEQ<sub>DF</sub>), 4,800 g WHO<sub>98</sub> TEQ<sub>DF</sub>  
22 (8,400 g I-TEQ<sub>DF</sub>), and 4,200 g WHO<sub>98</sub> TEQ<sub>DF</sub> (7,300 g I-TEQ<sub>DF</sub>) were incorporated into  
23 PCP-treated wood products in 1987, 1995, and 2000, respectively. It is unknown how much of  
24 the CDD/CDFs escape from the wood into the environment. Several field studies (Gurprasad et  
25 al., 1995; EPRI, 1995; Wan, 1995; Wan and Van Oostdam, 1995) demonstrate that CDDs/CDFs  
26 do apparently leach into soil from PCP-treated wood, but the studies do not provide release-rate  
27 data. No studies were located that provide any measured CDD/CDF volatilization rates from  
28 PCP-treated wood. Although CDDs/CDFs have very low vapor pressures, they are not bound to,  
29 nor do they react with, the wood in any way that would preclude volatilization. Lorber et al.  
30 (2002) compared the spatial distribution of CDD/CDF congeners in PCP-treated poles of  
31 different ages. A trend for dioxins to concentrate in the outer portions of the pole over time

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1 suggests migration within the poles, and this migration may result in some environmental  
2 release. However, this study could not quantify such releases. Several studies (Bremmer et al.  
3 [1994], Rappe [1995], Eduljee and Dyke [1996] and Douben et al. [1995]) have attempted to  
4 estimate potential CDD/CDF volatilization releases using conservative assumptions or modeling  
5 approaches, but these estimates span many orders of magnitude. Therefore, no estimate could be  
6 made as to what portion of the CDD/CDFs in products are released to the environment (Not  
7 quantifiable). The cumulative amounts of CDD/CDFs in PCP-treated wood can also be  
8 considered a potential reservoir source (see Chapter 11 for further discussion of this issue).

#### 10 **8.4.1.4. Products—2,4-D**

11 Although 2,4-Dichlorophenoxyacetic acid (2,4-D) is not a true chlorophenol, it is  
12 included in this section because it is produced from chlorophenols and, therefore, is closely  
13 associated. The available information on 2,4-D production and CDD/CDF levels was  
14 summarized in Chapter 11 of the original report. An estimated 28,100 MT of 2,4-D were used in  
15 the United States in 2000, making it one of the top 10 pesticides in terms of quantity used (EPA  
16 proprietary data). The pesticide 2,4-D is judged to have the potential for environmental release  
17 through its agricultural use. Since 1995, the chemical manufacturers of 2,4-D have been  
18 undertaking voluntary actions to significantly reduce the dioxin content of the product. No  
19 information is available on the level of dioxin contamination, if any, that may have been present  
20 in 2,4-D in 2000. An estimated 26,300 and 30,400 MT were used during 1995 and 1987,  
21 respectively (U.S. EPA, 1997c, 1988). On the basis of the average CDD/CDF congener  
22 concentrations in 2,4-D (not including OCDD and OCDF), the corresponding WHO<sub>98</sub> TEQ<sub>DF</sub>  
23 concentration is 1.1 µg/kg (0.7 µg I-TEQ<sub>DF</sub>/kg). Combining this TEQ concentration with the  
24 activity level estimates for 1995 and 1987 indicates that 28.9 g WHO<sub>98</sub> TEQ<sub>DF</sub> (18.4 g I-TEQ<sub>DF</sub>)  
25 were released in 1995 and 33.4 g WHO<sub>98</sub> TEQ<sub>DF</sub> (21.3 g I-TEQ<sub>DF</sub>) was released in 1987. No  
26 estimate can be made for 2000 because of the poor quality of existing information.

### 28 **8.4.2. Chlorobenzenes**

#### 29 **8.4.2.1. Process Description**

30 Chlorobenzenes can be produced via three methods: (1) electrophilic substitution of  
31 benzene (in liquid or vapor phase) with chlorine gas in the presence of a metal salt catalyst,

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1 (2) oxidative chlorination of benzene with HCl at 150 to 300EC in the presence of a metal salt  
2 catalyst, and (3) dehydrohalogenation of hexachlorocyclohexane wastes at 200 to 240EC with a  
3 carbon catalyst to produce trichlorobenzene, which can be further chlorinated to produce  
4 higher-chlorinated benzenes (Ree et al., 1988; Hutzinger and Fiedler, 1991b; Bryant, 1993).

5 All chlorobenzenes currently manufactured in the United States are produced by the  
6 electrophilic substitution process using liquid-phase benzene (i.e., temperature is at or below  
7 80EC). FeCl<sub>3</sub> is the most common catalyst employed. Although this method can be used to  
8 produce mono- through hexachlorobenzene, the extent of chlorination is controlled to yield  
9 primarily monochlorobenzene and dichlorobenzene. The finished product is a mixture of  
10 chlorobenzenes, and refined products must be obtained by distillation and crystallization (Bryant,  
11 1993).

#### 13 **8.4.2.2. Regulations for Chlorobenzenes**

14 EPA determined, as part of the Federal Insecticide, Fungicide, and Rodenticide Act  
15 (FIFRA) Data Call-In, that the 1,4-dichlorobenzene manufacturing processes used in the United  
16 States are not likely to form CDDs/CDFs. Mono-, di-, and trichlorobenzene are listed as  
17 potential precursor chemicals under the TSCA dioxin/furan test rule and are subject to reporting.  
18 In addition, EPA issued a Significant New Use Rule (SNUR) under Section 5(a)(2) of TSCA on  
19 December 1, 1993 (effective January 14, 1994) for pentachlorobenzene and  
20 1,2,4,5-tetrachlorobenzene (Federal Register, 1993). This rule requires that EPA be notified at  
21 least 90 days before the manufacture, import, or processing of either of these compounds in  
22 amounts of 10,000 pounds or greater per year per facility for any use. All registrations of  
23 pesticide products containing hexachlorobenzene were cancelled in the mid-1980s (Carpenter  
24 et al., 1986).

25 OSW promulgated land disposal restrictions on wastes (i.e., wastewaters and  
26 nonwastewaters) resulting from the manufacture of chlorobenzenes (40 CFR 268). Table 8-9  
27 lists all solid wastes for which EPA specifically regulates CDDs and CDFs, including  
28 chlorobenzene wastes, as hazardous constituents. The regulations prohibit the land disposal of  
29 these wastes until they are treated to a level below the routinely achievable DLs in the waste  
30 extract listed in Table 8-9 for each of the following congener groups: TCDDs, PeCDDs,  
31 HxCDDs, TCDFs, PeCDFs, and HxCDFs.

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1 The EPA Office of Water promulgated effluent limitations for facilities that manufacture  
2 chlorinated benzenes and discharge treated wastewater (40 CFR 414.70). These effluent  
3 limitations do not specifically address CDDs and CDFs. The following chlorinated benzenes are  
4 regulated: chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene,  
5 1,2,4-trichlorobenzene, and hexachlorobenzene. The effluent limitations for the individual  
6 regulated chlorinated benzenes are less than or equal to 77 µg/L for facilities that use biological  
7 end-of-pipe treatment and less than or equal to 196 µg/L for facilities that do not use biological  
8 end-of-pipe treatment.

9 Since at least 1993, U.S. commercial production of chlorobenzenes has been limited to  
10 monochlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, and, to a much lesser extent,  
11 1,2,4-trichlorobenzene. As noted above, CDD/CDF formation is not expected under the normal  
12 operating conditions of the processes currently used in the United States to produce these  
13 four chemicals. No tetra-, penta-, or hexachlorinated benzenes are now intentionally produced or  
14 used in the United States (Bryant, 1993). Thus, releases of CDDs/CDFs from the manufacture of  
15 chlorobenzenes in 1995 were estimated to be negligible. Because the information available on  
16 CDD/CDF content of mono-through pentachlorobenzene is very limited and is based primarily  
17 on unpublished European data, and because information on the chlorobenzene manufacturing  
18 processes in place during 1987 is not readily available, no emission estimates can be made for  
19 1987.

#### 20 21 **8.4.2.3. Products—Chlorobenzenes**

22 Chlorobenzenes have been produced in the United States since 1909. U.S. production  
23 operations were developed primarily to provide chemical raw materials for the production of  
24 phenol, aniline, and various pesticides based on the higher-chlorinated benzenes. Because of  
25 (incremental) changes in the processes used to manufacture phenol and aniline and the phaseout  
26 of highly chlorinated pesticides such as DDT and hexachlorobenzene, U.S. production of  
27 chlorobenzenes in 1988 had decreased to 50% of the peak production level, in 1969.

28 CDDs/CDFs can be produced inadvertently during the manufacture of chlorobenzenes by  
29 nucleophilic substitution and pyrolysis mechanisms (Ree et al., 1988). The criteria required for  
30 production of CDDs/CDFs via nucleophilic substitution are oxygen as a nuclear substituent (i.e.,  
31 presence of chlorophenols) and production or purification of the substance under alkaline

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1 conditions. Formation via pyrolysis requires reaction temperatures above 150°C (Ree et al.,  
2 1988; Hutzinger and Fiedler, 1991b). The liquid-phase electrophilic substitution process  
3 currently used in the United States does not meet either of these criteria. Although Ree et al.  
4 (1988) and Hutzinger and Fiedler (1991b) state that the criteria for formation of CDDs/CDFs via  
5 nucleophilic substitution may be present in the catalyst neutralization and purification/distillation  
6 steps of the manufacturing process; Opatick (1995) states that the chlorobenzene reaction  
7 product in U.S. processes remains mildly acidic throughout these steps.

8 Table 8-12 summarizes the very limited published information on CDD/CDF  
9 contamination of chlorobenzene products. The presence of CDDs/CDFs has been reported in  
10 tri-, penta-, and hexachlorobenzene. No CDDs/CDFs have been reported in mono- or  
11 dichlorobenzene. Conflicting data exist concerning the presence of CDDs/CDFs in  
12 trichlorobenzene. One study (Villanueva et al., 1974) detected no CDDs/CDFs in one sample of  
13 1,2,4-TCBz at a DL of 0.1 µg/kg. Hutzinger and Fiedler (1991b) reported unpublished results of  
14 a study by Dr. Hans Hagenmaier showing CDD/CDF congener group concentrations ranging  
15 from 0.02 to 0.074 µg/kg in a sample of mixed TCBz. Because the TCBz examined by  
16 Hagenmaier contained about 2% hexachlorocyclohexane, it is reasonable to assume that it was  
17 produced by dehydrohalogenation of hexachlorocyclohexane (a manufacturing process not  
18 currently used in the United States).

19 In conclusion, although there is some evidence that CDD/CDFs may be present in  
20 chlorobenzene products, insufficient information is available to make quantitative estimates.  
21 Accordingly, they are considered to be unquantifiable.

### 22 23 **8.4.3. Complex Plants**

24 In the year 2000, two facilities with an SIC code for plastic materials, synthetic resins,  
25 and nonvulcanizable elastomers reported dioxin releases under the EPA TRI program (U.S. EPA,  
26 2008). The sum of the air releases across these facilities was 5.6 g, which EPA estimates is  
27 equal to 0.5 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were reported. As explained in  
28 Chapter 1, the TRI data are not used to make quantitative estimates in this document but rather as  
29 supportive evidence that releases do occur.

30 In the year 2000, four facilities with an SIC code for industrial organic chemicals not  
31 classified elsewhere reported dioxin releases under the EPA TRI program (U.S. EPA, 2008).

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1 The sum of the air releases across these facilities was 153 g, which EPA estimates is equal to  
2 2.2 g WHO<sub>98</sub> TEQ<sub>DF</sub>. No releases to other media were reported. As explained in Chapter 1, the  
3 TRI data are not used to make quantitative estimates in this document but rather as supportive  
4 evidence that releases do occur.

5 The information presented in Dyke and Amendola (2007) was selected as the best basis  
6 for estimating CDD/CDF releases from facilities that produce combinations of chlorine and  
7 multiple chlorinated organic chemicals. The 10 complex chemical plants covered in this study  
8 are believed to represent most facilities of this type in the United States. Therefore, it was  
9 unnecessary to develop emission factors to estimate releases from untested facilities. Dyke and  
10 Amendola reported their release estimates in I-TEQs, but stated that WHO<sub>98</sub> values were usually  
11 less than 20% different. Using the water congener profile, the WHO<sub>98</sub> values were computed to  
12 be only 4% higher than the I-TEQs. On this basis the I-TEQs were assumed to be equivalent to  
13 the WHO<sub>98</sub> TEQs for all releases. The Dyke and Amendola release estimates are specific to the  
14 year 2000. Because the chemical production rates and technologies used at these facilities have  
15 changed significantly, no release estimates could be made for 1987 and 1995.

16 Table 8-13 shows the amount of CDD/CDFs that are sent to off-site incinerators and  
17 landfills. The releases from incineration are included in the estimates presented for hazardous  
18 waste incinerators (see Section 3.2). The amounts sent to secure landfills (118 g I-TEQ in 2000)  
19 are not considered to be environmental releases.

20 The releases to all media from the complex chemical plants are presented in Table 8-13.  
21 The inventory decision criteria and releases to all media are summarized below:

22

<b>Inventory Decision Criteria for Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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

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<b>Complex Chemical Plants Producing Chlorine and a Variety of Chlorinated Organics</b>	
<b>Air Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—Not available.</li> <li>• 2000—5 g (WHO<sub>98</sub> or I-TEQ).</li> </ul>	
<b>Water Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—Not available.</li> <li>• 2000—25 g (WHO<sub>98</sub> or I-TEQ).</li> </ul>	
<b>Solid Residue Releases</b>	
<b>Landfarmed</b>	
<ul style="list-style-type: none"> <li>• 1987—Not available.</li> <li>• 1995—Not available.</li> <li>• 2000—1 g (WHO<sub>98</sub> or I-TEQ).</li> </ul>	
<b>Products</b>	
<b>PVCs</b>	
<ul style="list-style-type: none"> <li>• 1987—Not quantifiable.</li> <li>• 1995—Not quantifiable.</li> <li>• 2000—Not quantifiable.</li> </ul>	
<b>Pentachlorophenols</b>	
<ul style="list-style-type: none"> <li>• 1987—Not quantifiable.</li> <li>• 1995—Not quantifiable.</li> <li>• 2000—Not quantifiable.</li> </ul>	
<b>2,4-Dichlorophenoxy acetic acid (2,4-D)</b>	
<ul style="list-style-type: none"> <li>• 1987—33 g WHO<sub>98</sub> TEQ<sub>DF</sub> (21 g I-TEQ<sub>DF</sub>).</li> <li>• 1995—29 g WHO<sub>98</sub> TEQ<sub>DF</sub> (18 g I-TEQ<sub>DF</sub>).</li> <li>• 2000—Not quantifiable.</li> </ul>	
<b>Chlorobenzenes</b>	
<ul style="list-style-type: none"> <li>• 1987—Not quantifiable.</li> <li>• 1995—Not quantifiable.</li> <li>• 2000—Not quantifiable.</li> </ul>	

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## 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.

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1 **8.5.1. Air Releases**

2 Releases associated with sewage sludge incineration are covered in Section 3.5.

4 **8.5.2. Water Releases**

5 No changes were made to the emission factors, activities, or release estimates. The  
6 CRWQCB data (memorandum dated March 21, 1996, from Lila Tang, California Regional  
7 Water Quality Control Board, to David Cleverly, U.S. EPA) were the only U.S. data that  
8 provided TEQ estimates for CDD/CDF levels in wastewaters from sewage treatment plants.  
9 Accordingly, the concentration from this study (0.27 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L [0.29 pg I-TEQ<sub>DF</sub>/L])  
10 was assumed to apply to all reference years. However, these data were from plants in the San  
11 Francisco area and cannot be considered to be representative of the 16,000-plus POTWs  
12 nationwide. Therefore, the emission factor was considered preliminary. Activity estimates were  
13 derived from EPA surveys as described in US EPA (2006) and are presented in the release  
14 summary below.

16 **8.5.3. Solid Residue Releases**

17 The large U.S. studies (U.S. EPA, 1996b, 2002d; Green et al., 1995; Cramer et al., 1995)  
18 were selected as the best basis for estimating emission factors. Because the mean I-TEQ<sub>DF</sub>  
19 concentration values reported in the 1988/1989 sewage sludge survey (U.S. EPA, 1996b) and the  
20 1995 survey (Green et al., 1995; Cramer et al., 1995) were very similar, the estimated amounts of  
21 TEQs that may have been present in sewage sludge and released to the environment in 1987 and  
22 1995 were assumed to be the same. These values were estimated using the average of the mean  
23 concentration values (nondetects equal to DLs) reported by EPA (1996b) (50 ng I-TEQ<sub>DF</sub>/kg)  
24 and by Green et al. (1995) and Cramer et al. (1995) (36.3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg  
25 [47.7 ng I-TEQ<sub>DF</sub>/kg]). Therefore, the overall average mean emission factor for reference years  
26 1987 and 1995 is 36.3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (48.9 ng I-TEQ<sub>DF</sub>/kg). The emission factor of  
27 14 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (15 ng I-TEQ<sub>DF</sub>/kg), as calculated from the 2001 survey (U.S. EPA,  
28 2002d), appears to be the most reasonable TEQ emission factor estimate for reference year 2000  
29 because this estimate is nationally weighted on the basis of wastewater flow rates of POTWs  
30 operating in the United States in 2001 (see Table 8-14—note that the values in this table were

1 recalculated, resulting in minor decreases compared to the original document, which presented  
2 the data in Table 8-40).

3 No changes were made to the sludge activity results, which were presented in  
4 three categories: land applied (includes advanced treatment since this refers to composting,  
5 which is generally done in unlined containers), landfilled (includes sludge landfills, codisposal  
6 landfills, and surface disposal), and product (includes distribution/marketing and beneficial use).  
7 The summary table below presents the activities and releases for sludge, which is land applied or  
8 used in products. These are assumed to result in environmental releases. The landfilled sludges  
9 are not included in the summary because they are not considered to be environmental releases.  
10 The activity estimates for the landfilled sludge were 2.37 million dry MT in 1987,  
11 1.10 million dry MT in 1995, and 0.90 million dry MT in 2000. The CDD/CDF amounts in the  
12 landfilled sludge were estimated as follows:

13

- 14 • 1987—86 g WHO TEQ<sub>DF</sub> (120 g I-TEQ<sub>DF</sub>/kg)
- 15 • 1995—40 g WHO TEQ<sub>DF</sub> (54 g I-TEQ<sub>DF</sub>/kg)
- 16 • 2000—13 g WHO TEQ<sub>DF</sub> (14 g I-TEQ<sub>DF</sub>/kg)

17

#### 18 **8.5.4. Products**

19 The sewage sludge emission factors described above were also applied to the swage  
20 sludge used as products. No changes were made to the activity estimates. All of these values  
21 and the resulting release estimates are presented in the summary table below.

22

#### 23 **8.5.5. Releases**

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

25

<b>Inventory Decision Criteria for Municipal Wastewater Treatment Plants</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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

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<b>Municipal Wastewater Treatment Plants</b>
<b>Air Releases</b>
None.
<b>Water Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—0.27 pg WHO TEQ<sub>DF</sub>/L (0.29 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> <li>• 1995—0.27 pg WHO TEQ<sub>DF</sub>/L (0.29 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> <li>• 2000—0.27 pg WHO TEQ<sub>DF</sub>/L (0.29 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—47.8 trillion L.</li> <li>• 1995—44.5 trillion L.</li> <li>• 2000—54.0 trillion L.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—13 g WHO TEQ<sub>DF</sub>/yr (14 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> <li>• 1995—12 g WHO TEQ<sub>DF</sub>/yr (13 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> <li>• 2000—15 g WHO TEQ<sub>DF</sub>/yr (16 g I-TEQ<sub>DF</sub>/yr) (Preliminary).</li> </ul>
<b>Solid Residue Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—36 ng WHO TEQ<sub>DF</sub>/kg (49 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—36 ng WHO TEQ<sub>DF</sub>/kg (49 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—14 ng WHO TEQ<sub>DF</sub>/kg (15 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>
<b>Activity Levels</b>
<p><i>Land Applied</i></p> <ul style="list-style-type: none"> <li>• 1987—1.71 million dry MT/yr.</li> <li>• 1995—3.20 million dry MT/yr.</li> <li>• 2000—3.60 million dry MT/yr.</li> </ul>
<b>Releases</b>
<p><i>Land Applied</i></p> <ul style="list-style-type: none"> <li>• 1987—62 g WHO TEQ<sub>DF</sub> (84 g I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—120 g WHO TEQ<sub>DF</sub> (160 g I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—50 g WHO TEQ<sub>DF</sub> (54 g I-TEQ<sub>DF</sub>/kg).</li> </ul>

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Municipal Wastewater Treatment Plants (continued)	
Products	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—36 ng WHO TEQ<sub>DF</sub>/kg (49 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—36 ng WHO TEQ<sub>DF</sub>/kg (49 ng I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—14 ng WHO TEQ<sub>DF</sub>/kg (15 ng I-TEQ<sub>DF</sub>/kg).</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—0.07 MMT.</li> <li>• 1995—0.50 MMT.</li> <li>• 2000—0.50 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—3 g WHO TEQ<sub>DF</sub> (3 g I-TEQ<sub>DF</sub>/kg).</li> <li>• 1995—18 g WHO TEQ<sub>DF</sub> (24 g I-TEQ<sub>DF</sub>/kg).</li> <li>• 2000—7 g WHO TEQ<sub>DF</sub> (8 g I-TEQ<sub>DF</sub>/kg).</li> </ul>

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### 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.

<b>Textiles Manufacturing and Dry Cleaning</b>
<b>Releases</b>
Not quantifiable.

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**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.

<b>Chloranil Imports</b>
<b>Releases</b>
Not quantifiable.

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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.

<b>Phthalocyanine Dyes and Printing Inks</b>
<b>Releases</b>
Not quantifiable.

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**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.

21

**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.

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1 **8.11.1. Process Description**

2 Most residential septic systems consist of a septic tank and drainage field or dry well.  
3 The household waste flows by gravity into the septic tank where biological digestion occurs and  
4 solids settle out. The overflow goes into the drainage field or dry well where it slowly percolates  
5 into the ground.

6  
7 **8.11.2. Regulations**

8 None specific to dioxins.  
9

10 **8.11.3. Emission Factor**

11 No measurements were found on the amount of CDD/CDF excreted by people. However  
12 studies have been done with dairy cattle involving measurements of dioxins in their feed, milk,  
13 feces, and urine under carefully controlled settings (Winters et al., 2000; Lorber et al., 2000;  
14 McLachlan et al., 1990). These studies found that 50% to 100% of both TEQs and individual  
15 congeners in the feed were recovered in the milk and feces. For purposes of a preliminary  
16 estimate, it is assumed here that 100% of the dioxin TEQs ingested by people are excreted in the  
17 feces. Clearly this is an overestimate particularly for lactating mothers. For the general  
18 population, adult daily intakes are estimated to average 43 pg WHO<sub>98</sub> TEQ<sub>DF</sub> for CDD/CDFs and  
19 23 pg WHO<sub>98</sub> TEQ<sub>PCB</sub> for PCBs (U.S. EPA, 2004). It is assumed that 30 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/day  
20 represents a whole population average (children plus adults) for the CDD/CDFs. Assuming that  
21 two thirds of an individual's excretion occurs at their residence, 20 pg WHO<sub>98</sub>TEQ<sub>DF</sub>/day is  
22 discharged to the septic system. It is also assumed that no TEQ degradation or formation occurs  
23 in the septic system.

24 Septic systems are designed to trap the solid components of sewage in a septic tank. The  
25 tank is periodically pumped, and the contents are discharged to a municipal wastewater treatment  
26 system (these releases are covered in Section 8.5). Many of the smaller particles and oily  
27 components will flow into the drainage field. The fraction CDD/CDFs released to the drainage  
28 field will depend largely on the solids trapping efficiency of the system, which depends on  
29 variables such as tank size, flow rates, and pumping frequency. For the purposes of a  
30 preliminary estimate, this is assumed to be 50%. Thus, the overall emission factor is assumed to  
31 be 10 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/day-person and would be applicable to all reference years. Considering

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1 the lack of direct feces measurements and multiple assumptions required for this estimate, it is  
2 given a preliminary confidence rating.

3

4 **8.11.4. Activity**

5 Septic systems serve 25% of the U.S. population (U.S. EPA, 2005). The total U.S.  
6 population is estimated to be 242 million in 1987, 263 million in 1995, and 300 million in 2000  
7 (U.S. DOC, 2000). Multiplying by 25%, the activity for each reference year is 61 million in  
8 1987, 66 million in 1995, and 75 million in 2000.

9

10 **8.11.5. Releases**

11 The releases from septic systems will occur via the liquid effluent that drains into the soil.  
12 It is included with the solid residues because the release is to land.

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

14

<b>Inventory Decision Criteria for Residential Septic Systems</b>			
	<b>Air</b>	<b>Water</b>	<b>Solids Products</b>
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

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16

<b>Residential Septic Systems</b>
<b>Air Releases</b>
None.
<b>Water Releases</b>
None.
<b>Solid Residue Releases</b>
<b>Emission Factors</b>
<ul style="list-style-type: none"> <li>• 1987—10 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/day-person (Preliminary).</li> <li>• 1995—10 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/day-person (Preliminary).</li> <li>• 2000—10 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/day-person (Preliminary).</li> </ul>
<b>Activity Levels</b>
<ul style="list-style-type: none"> <li>• 1987—61 million people.</li> <li>• 1995—66 million people.</li> <li>• 2000—75 million people.</li> </ul>
<b>Releases</b>
<ul style="list-style-type: none"> <li>• 1987—0.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 1995—0.2 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> <li>• 2000—0.3 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary).</li> </ul>

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**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 <sup>a</sup>	1.02	2.21	2.45	0.7
Total 2,3,7,8-CDF <sup>a</sup>	152.37	341.7	339.6	303
Total I-TEQ <sub>DF</sub> <sup>a</sup>	14.2	30.5	30.2	27.7
Total WHO <sub>98</sub> TEQ <sub>DF</sub> <sup>a</sup>	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 <sup>a</sup>	263.14	661.48	647.76	--

<sup>a</sup>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).

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**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 <sub>98</sub> TEQ <sub>DF</sub>	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**

<b>Congener</b>	<b>PPG Industries Natrium, WV</b>
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 <sub>DF</sub>	0.034
Total WHO <sub>98</sub> TEQ <sub>DF</sub>	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 <sup>a</sup>		
		Air	Water	Landfill	Landfarm	Landfill	Incineration	Well Inj
Occidental—Mobile, AL	Cl <sub>2</sub> (membrane-cell), caustic potash, sodium silicate		$3.60 \times 10^{-5}$			0.83		
Confidence Rating			H/H			H/H		
Occidental—Battleground, TX	Cl <sub>2</sub> (diaphragm-cell), NaOH		$4.80 \times 10^{-4}$					
Confidence Rating			H/H					
Occidental—Deer Park, TX (CA)	Cl <sub>2</sub> (mercury/diaphragm-cell), NaOH		0.54			0.38		
Confidence Rating			H/H			R/H		
Occidental—Delaware City, DE	Cl <sub>2</sub> (mercury-cell), NaOH, caustic potash,		$1.30 \times 10^{-4}$			0.81	$3.50 \times 10^{-6}$	
Confidence Rating			R/H			H/H	H/H	
Occidental—Hahnville (Taft), LA	Cl <sub>2</sub> (mercury/diaphragm-cell), NaOH, sulfur		1.08			0.2	$9.60 \times 10^{-9}$	0.04
Confidence Rating			H/H			H/H	H/H	R/H
Occidental—Muscle Shoals, AL	Cl <sub>2</sub> (mercury-cell) and caustic potash		$8.70 \times 10^{-8}$			0.38		
Confidence Rating			H/H			H/H		
PPG Industries—Natrium, WV	Cl <sub>2</sub> (mercury/diaphragm-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

<sup>a</sup>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 ( $\mu\text{g}/\text{kg}$ ) 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 <sub>DF</sub>	20	5,928	3.2
Total WHO <sub>98</sub> TEQ <sub>DF</sub>	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	<sup>a</sup>
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

<sup>a</sup>Congener group concentration reported in source is not consistent with reported congener concentrations.

Source: Stringer et al. (1995).

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**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 <sup>d</sup>		
	No. detects/ samples <sup>a</sup>	Range <sup>b</sup> (ng/kg)		No. of detects/ samples	Range <sup>c</sup> (ng/kg)		No. detects/ samples	Range <sup>e</sup> (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

<sup>a</sup>Two of these 22 samples were duplicate samples from two sites. The results were averaged and treated as one sample for each site.

<sup>b</sup>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.

<sup>c</sup>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.

<sup>d</sup>“Sales” EDC is defined as EDC sold commercially for non-VCM uses or exported from the United States.

<sup>e</sup>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 <sup>a</sup>	
		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

<sup>a</sup>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 <sup>a</sup>	2,4-DCP <sup>a</sup>	2,6-DCP <sup>a</sup>	2,4,5-TrCP (Na salt) <sup>a</sup>	2,4,5-TrCP <sup>a</sup>	2,4,6-TrCP <sup>a</sup>	2,4,6-TrCP (Na salt) <sup>b</sup>	2,3,4,6-TeCP <sup>a</sup>	2,3,4,6-TeCP (Na salt) <sup>b</sup>
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	--	--	--	--	--	--	--	--	--

<sup>a</sup>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.

<sup>b</sup>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<sup>a</sup>**

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

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<b>Table 8-9. Summary of specific dioxin containing wastes that must comply with land disposal restrictions<sup>a</sup> (continued)</b>			
<b>EPA hazardous waste number</b>	<b>Waste description</b>	<b>Land disposal restriction effective date</b>	<b>Regulated waste constituent</b>
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

<sup>a</sup>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.

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**Table 8-10. CDD/CDF concentrations (historical and current) (µg/kg) in technical-grade pentachlorophenol (PCP) products**

Congener/ congener group	1973 <sup>a</sup>	1978 <sup>b</sup>	1979 <sup>c</sup>	1984 <sup>d</sup>	1985 <sup>e</sup>	1986 <sup>e</sup>	1987 <sup>f</sup>	1987 <sup>g</sup>	1985E88 <sup>h</sup>	1991 <sup>i</sup>	1988E99 <sup>e</sup>	1988E99 <sup>j</sup>	Unknown <sup>k</sup>
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 (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 <sup>l</sup>	--	--	--	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 <sup>l</sup>	--	--	--	130,000	260,159	268,238	130,076	158,230	262,469	170,000	--	--	22,280
Total I-TEQ <sub>DF</sub> <sup>1</sup>	--	--	--	1,970	4,445	2,735	1,853	2,321	4,173	≥1,270	--	--	810
Total WHO <sub>98</sub> TEQ <sub>DF</sub> <sup>1</sup>	--	--	--	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 <sup>l</sup>	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) ( $\mu\text{g}/\text{kg}$ ) in technical-grade pentachlorophenol (PCP) products (continued)**

<sup>a</sup>Source: Buser and Bosshardt (1976); mean of 10 samples of Ahigh@ CDD/CDF-content PCP received from Swiss commercial sources in 1973.

<sup>b</sup>Source: Rappe et al. (1978); sample of U.S. origin, Apresumably prepared by alkaline hydrolysis of hexachlorobenzene.@

<sup>c</sup>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).

<sup>d</sup>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).

<sup>e</sup>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.

<sup>f</sup>Source: Hagenmaier and Brunner (1987); sample of Witophen P (Dynamit Nobel-Lot no. 7777) (obtained in Germany).

<sup>g</sup>Source: Hagenmaier and Brunner (1987); sample of PCP produced by Rhone Poulenc (obtained in Germany).

<sup>h</sup>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.

<sup>i</sup>Source: Harrad et al. (1991); PCP-based herbicide formulation from the New York State Department of Environmental Conservation.

<sup>j</sup>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).

<sup>k</sup>Source: Schecter et al. (1997); sample found stored in a barn in Vermont.

<sup>l</sup>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 <sup>a</sup>	1973 <sup>b</sup>	1973 <sup>c</sup>	1987 <sup>d</sup>	1987 <sup>e</sup>	1992 <sup>f</sup>	1980s <sup>g</sup>
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 <sup>h</sup>	--	--	--	53,062.7	36,289	1,059,252.8	118,878.3
Total 2,3,7,8-CDF <sup>h</sup>	--	--	--	38,794.6	4,498.6	126,492.3	43,841
Total I-TEQ <sub>DF</sub> <sup>h</sup>	--	--	--	452	89.5	3,374	1,201
Total WHO <sub>98</sub> TEQ <sub>DF</sub> <sup>h</sup>	--	--	--	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 <sup>h</sup>	30,200	15,980	235,990	117,859	43,752	1,348,751	378,742

<sup>a</sup>Source: Firestone et al. (1972); mean of two samples of PCP-Na obtained in the United States between 1967 and 1969.

<sup>b</sup>Source: Buser and Bosshardt (1976); mean of five samples of Alow@ CDD/CDF-content PCP-Na received from Swiss commercial sources.

<sup>c</sup>Source: Buser and Bosshardt (1976); sample of Ahigh@ CDD/CDF-content PCP-Na received from a Swiss commercial source.

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**Table 8-11. Historical CDD/CDF concentrations ( $\mu\text{g}/\text{kg}$ ) in pentachlorophenol Na (PCP Na) (continued)**

<sup>d</sup>Source: Hagenmaier and Brunner (1987); sample of Dowicide-G purchased from Fluka; sample obtained in Germany.

<sup>e</sup>Source: Hagenmaier and Brunner (1987); sample of Preventol PN (Bayer AG); sample obtained in Germany.

<sup>f</sup>Source: Santl et al. (1994); 1992 sample of PCP-Na from Prolabo, France.

<sup>g</sup>Source: Palmer et al. (1988); sample of a PCP-Na formulation collected from a closed sawmill in California in the late 1980s.

<sup>h</sup>Calculated assuming nondetect values were zero.

ND = Not detected (value in parenthesis is the detection limit).

-- = No information given.

**Table 8-12. CDD/CDF concentrations ( $\mu\text{g}/\text{kg}$ ) in chlorobenzenes**

<b>Congener/ congener group</b>	<b>MCBz<sup>a</sup></b>	<b>1,2-DCBz (for synthesis)<sup>a</sup></b>	<b>1,2,4-TrCBz (Apure@)<sup>b</sup></b>	<b>Mixed TrCBz (47%)<sup>a</sup></b>	<b>1,2,4,5-TCBz (99%)<sup>a</sup></b>	<b>PeCBz (98%)<sup>a</sup></b>	<b>HCBz (97%)<sup>a</sup></b>	<b>HCBz<sup>b</sup></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
<b>Total CDD/CDF</b>	<b>ND</b>	<b>0.8</b>	<b>ND</b>	<b>1.9</b>	<b>6.5</b>	<b>0.3</b>	<b>10,455</b>	<b>400B270,300</b>

<sup>a</sup>Source: Hutzinger and Fiedler (1991b); unpublished results of tests performed at the University of Bayreuth, Germany, and by Dr. H. Hagenmaier.

<sup>b</sup>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 <sup>a</sup>	
		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	Cl <sub>2</sub> (diaphragm-cell), NaOH, EDC, VCM	1.61	0.018			1.47	
Confidence Rating		RH/H	H/H			H/H	
PPG Industries—Lake Charles, LA	Cl <sub>2</sub> (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	Cl <sub>2</sub> , solvents, other chlorinated organics	0.037	1.07				0.208
Confidence Rating		R/H	R/H				
Occidental—Niagara Falls	Cl <sub>2</sub> , NaOH, organic chemicals	$3.80 \times 10^{-3}$	$1.40 \times 10^{-3}$			0.028	210
Confidence Rating		H/H	H/H			R/H	R/H
Company B, Plant B2	Cl <sub>2</sub> , EDC, solvents	$8.38 \times 10^{-3}$	$3.72 \times 10^{-1}$				

**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 <sup>a</sup>	
		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

<sup>a</sup>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**

<b>Congener</b>	<b>Nondetect set to ½ detection limit</b>	<b>Nondetect set to zero</b>
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 <sub>98</sub> TEQ <sub>DF</sub>	23	14
Average total I-TEQ <sub>DF</sub>	27	15

Source: EPA (2002d).

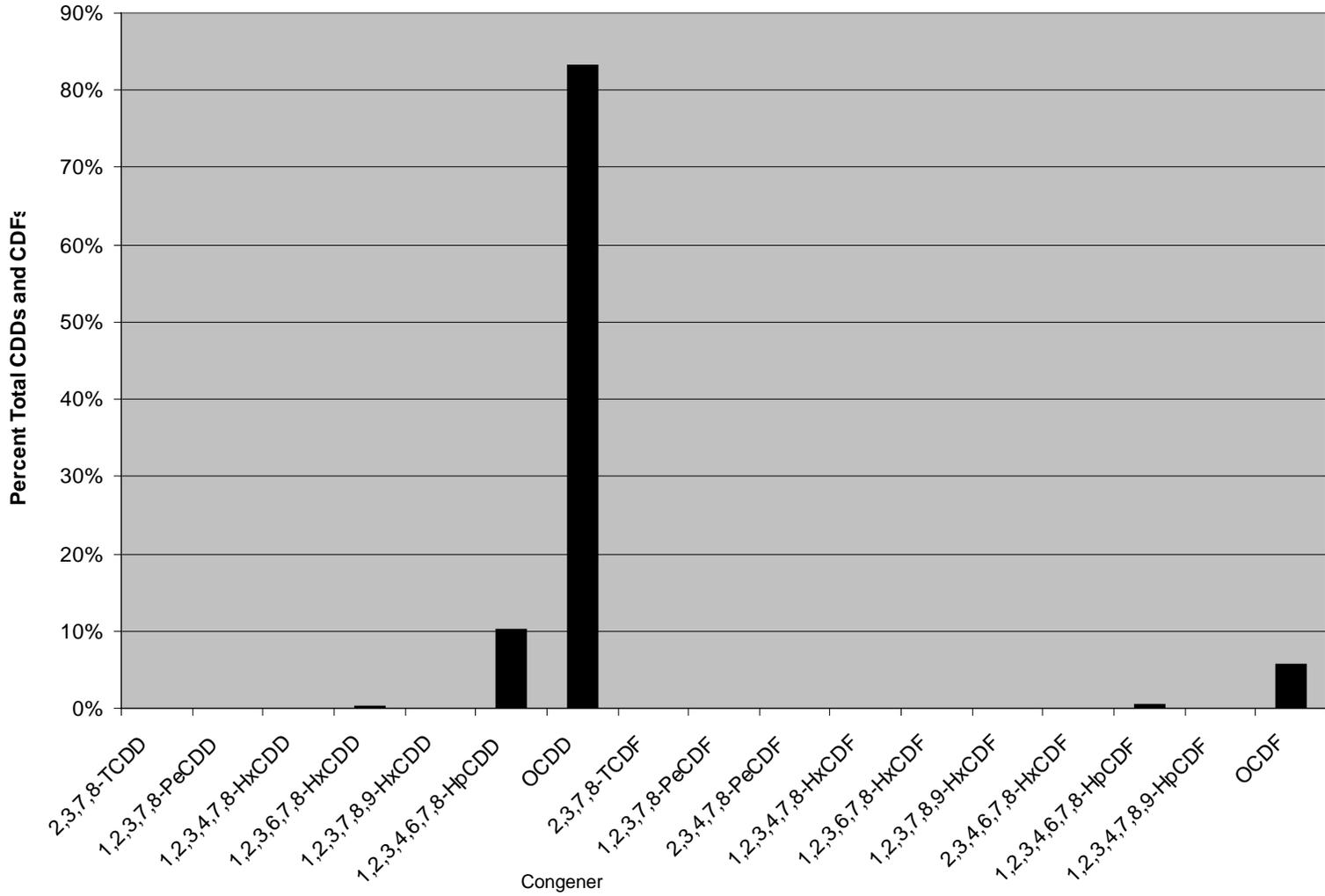


Figure 8-1. Congener profile for technical-grade PCP (developed from data in last column in Table 8-10).

## 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).

<b>Biotransformation of Chlorophenols</b>
<b>Releases to Soil</b>
Not quantifiable.

1 **9.1.2. Biotransformation of Higher CDDs/CDFs**

2 As discussed in the original report, results of several studies that examined the fate of a  
3 range of CDD/CDF congeners in pure cultures, sediments, and sludges indicate that under  
4 certain conditions, some CDD/CDF congeners will undergo biodegradation to form  
5 lower-chlorinated (and possibly more toxic) CDDs/CDFs. However, the extent to which more  
6 toxic CDDs/CDFs are formed in the environment via this mechanism cannot be estimated at this  
7 time.

8 Therefore, these releases are not quantifiable.

<b>Biotransformation of Higher CDDs/CDFs</b>
<b>Releases to Soil</b>
Not quantifiable.

9 **9.1.3. Biotransformation of Animal Manure**

10 Because livestock and poultry manure can provide valuable organic material and  
11 nutrients for crop and pasture growth, most of the animal manure generated at commercial farms  
12 and animal feed lots is applied to farmland as fertilizer. To the extent dioxin-like compounds  
13 may contaminate animal manures, the practice of land-spreading animal waste may result in  
14 releases of CDDs/CDFs to the open and circulating environment.

15 Mass balance studies have shown that no new formation of dioxins and furans appears to  
16 occur within a cow (Winters et al., 2000; Lorber et al., 2000; McLachlan et al., 1990). These  
17 studies have involved measuring the dioxins present in the feeds provided to dairy cows and then  
18 measuring the dioxins in the cow milk, feces, and urine in carefully controlled settings. Studies  
19 by EPA (Winters et al., 2000; Lorber et al., 2000) involved four cows, sampled three times  
20 between July and November of 1997. Preliminary testing on urine showed nondetects as  
21 expected, so this matrix was not included in further testing. The tests were designed to represent  
22 typical conditions (feed types, dairy cow housing, etc.) in the United States with regard to the  
23 production of milk. The feed and feces concentrations ranged from 0.13 to

1 0.30 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg dry weight basis, and milk concentrations ranged from 0.53 to  
2 0.96 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg lipid basis. The feces concentrations in these lactating cows were  
3 about one order of magnitude lower than that measured by Stevens and Jones (2003) in the  
4 United Kingdom (U.K.) (see Table 9-1). A mass balance was determined by dividing the mass  
5 of CDD/CDFs present in feces and milk by the mass in the feed and then multiplying by 100% (a  
6 finding of 100% suggests that the dioxins excreted in milk and feces equals that in the feed; a  
7 finding greater than 100% suggests formation). These matrices were sampled once the cows  
8 were well into lactation, so an assumption of steady state was reasonable. The mass balance of  
9 both TEQs and individual congeners ranged from about 50 to 100%, suggesting no internal  
10 formation of CDD/CDFs by the cows. The average mass balance over 17 congeners was 73%.  
11 McLachlan et al. (1990) conducted a similar experiment with one cow in a background setting  
12 and also found mass balances between 50 and 100%, with an average of 75% over all  
13 17 CDD/CDF congeners.

14 As discussed in the original report, reasonably good data are available on the generation  
15 rates of livestock manure. However, limited data are available on CDD/CDF levels in livestock  
16 manure. Further, mass balance studies on lactating cows suggest that no new formation of  
17 CDD/CDFs are occurring. Thus, while the land application of farm animal manure is a potential  
18 land release, it is concluded that insufficient data are available to quantify these releases, and  
19 because of the mass balance studies, these may be better characterized as a redistribution rather  
20 than a new formation. Accordingly, EPA currently considers this source to be unquantifiable in  
21 terms of dioxin emissions.

<b>Biotransformation of Animal Manure</b>
<b>Releases to Soil</b>
Not quantifiable.

22

## 23 **9.2. PHOTOCHEMICAL TRANSFORMATIONS**

24 A number of researchers have demonstrated that CDD/CDFs can be formed via various  
25 types of photochemical transformations.

1 **9.2.1. Photolysis of PCP**

2 As discussed in the original report, several studies have demonstrated that photolysis of  
3 PCP may lead to the formation of CDD/CDFs; however, the information is considered  
4 inadequate to estimate releases of CDD/CDFs to the environment.

<b>Photolysis of PCP</b>
<b>Releases to Wood or Air</b>
Not quantifiable.

5 **9.2.2. Photolysis of Higher CDDs/CDFs**

6 As discussed in the original report, a number of studies have demonstrated that photolysis  
7 of higher CDD/CDFs may lead to the formation of CDD/CDFs; however, the information is  
8 considered inadequate to estimate releases of CDD/CDFs to the environment.

<b>Photolysis of Higher CDDs/CDFs</b>
<b>Releases to Air, Water, or Soil</b>
Not quantifiable.

9 **9.2.3. Photolysis in Water**

10 As discussed in the original report, a number of studies have demonstrated that photolysis  
11 in water may lead to the formation of CDD/CDFs; however, the information is considered  
12 inadequate to estimate releases of CDD/CDFs to the environment.

<b>Photolysis in Water</b>
<b>Releases to Water</b>
Not quantifiable.

13 **9.2.4. Photolysis on Soil Surfaces**

14 As discussed in the original report, studies have demonstrated that photolysis on soil  
15 surfaces may lead to the formation of CDD/CDFs; however, the information is considered  
16 inadequate to estimate releases of CDD/CDFs to the environment.

<b>Photolysis on Soil</b>
<b>Releases to Soil</b>
Not quantifiable.

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1 **9.2.5. Photolysis on Vegetation**

2 As discussed in the original report, studies have demonstrated that photolysis on  
3 vegetation may lead to the formation of CDD/CDFs; however, the information is considered  
4 inadequate to estimate releases of CDD/CDFs to the environment.

<b>Photolysis on Vegetation</b>
<b>Releases to Biota</b>
Not quantifiable.

5 **9.2.6. Photolysis in Air**

6 As discussed in the original report, studies have demonstrated that photolysis in air may  
7 lead to the formation of CDD/CDFs; however, the information is considered inadequate to  
8 estimate releases of CDD/CDFs to the environment.

<b>Photolysis in Air</b>
<b>Releases to Air</b>
Not quantifiable.

9 **9.3. CDDS/CDFS IN BALL CLAY**

10 As discussed in the original report, studies have demonstrated that CDD/CDFs are found  
11 naturally in ball clay. Releases from ball clay may occur when it is disturbed during mining and  
12 subsequent processing. Accordingly, such releases have both a natural and an anthropogenic  
13 aspect to them. Multiplication of the mean WHO<sub>98</sub> TEQ<sub>DF</sub> concentration in mined ball clay by  
14 the total amount of ball clay mined in 1995 gives an estimate of 1,502 g WHO<sub>98</sub> TEQ<sub>DF</sub>  
15 (U.S. EPA, 2006). It is unknown how much of these CDD/CDFs contained in mined ball clay  
16 are released to the environment during the mining, initial refining, and product handling. Most  
17 ball clay is used to produce ceramic products where releases may occur from processes such as  
18 drying or high-temperature vitrification. The temperatures found in ceramic kilns vary but can  
19 reach levels needed for both volatilization and destruction of CDD/CDFs. No stack  
20 measurement data are available from these facilities, so there is insufficient evidence to make  
21 even a preliminary estimate of releases.

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<b>Ball Clay</b>
<b>Releases to Air</b>
Not quantifiable.

**Table 9-1. CDD and CDF concentrations (ng/kg dry weight) in samples of animal manure in the United Kingdom**

<b>Congener</b>	<b>Cows<sup>a</sup> (n = 6) (mean)</b>	<b>Cows<sup>b</sup> (n = 10) (mean)</b>	<b>Sheep<sup>a</sup> (n = 1)</b>	<b>Pig<sup>a</sup> (n = 1)</b>	<b>Chicken<sup>a</sup> (n = 1)</b>
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
<b>Total 2,3,7,8-CDD</b>	<b>590.1</b>	<b>62.3</b>	<b>65.2</b>	<b>12.3</b>	<b>15.7</b>
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
<b>Total 2,3,7,8-CDF</b>	<b>58.9</b>	<b>5.0</b>	<b>18.3</b>	<b>1.6</b>	<b>1.9</b>
<b>Total CDD/CDF</b>	<b>649</b>	<b>67.4</b>	<b>83.5</b>	<b>13.9</b>	<b>17.6</b>
<b>WHO<sub>98</sub> TEQ</b>	<b>3.6</b>	<b>0.2</b>	<b>2.1</b>	<b>0.2</b>	<b>0.2</b>

Sources: <sup>a</sup>Stevens and Jones (2003); <sup>b</sup>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.

1       **10. SOURCES OF DIOXIN-LIKE POLYCHLORINATED BIPHENYLS (PCBS)**  
2  
3

4           This chapter estimates releases of dioxin-like PCB congeners to the environment. PCB  
5 releases from media reservoirs (i.e., soil, sediment, and water) are covered in Chapter 11. This  
6 chapter covers other PCB sources, primarily conventional point sources. These sources are  
7 assumed to have contemporary formation releases. This is uncertain, though, because some  
8 portion of these releases may be passed through from inputs to outputs rather than new  
9 formation. Both Chapters 10 and 11 contain information on releases associated with PCB  
10 products.

11  
12       **10.1. GENERAL FINDINGS OF THE EMISSIONS INVENTORY**

13           The primary changes to this chapter include the addition of several new source  
14 categories, addition of background information to a number of the other sources, and minor  
15 changes to the release estimates. Additionally, the release summary table (see Table 10-1) has  
16 been reformatted to match the new one used for CDD/CDFs.

17           Relatively few sources have well-characterized releases of dioxin-like PCBs. As shown  
18 in Table 10-1, 2 sources had quantitative release estimates, 6 sources had preliminary release  
19 estimates and 9 sources were identified as being unquantifiable. Although the information is  
20 limited, it suggests that, in terms of TEQs, PCB releases are much lower than CDD/CDF  
21 releases.

22           Two potential source categories that could not be addressed are contaminated PCB sites  
23 and wastes with less than 50-ppm PCB (which are not regulated under TSCA). No information  
24 was found that would allow evaluation of releases from these sources.

25           The original report concluded that it is likely that no significant releases of newly formed  
26 dioxin-like PCBs are occurring in the United States. This is based on three arguments. First,  
27 although the data are limited, the inventory presented here suggests that new releases are low in  
28 comparison to the amounts currently present in the environment. As shown in Table 10-1, the  
29 total quantitative release estimates for 2000 sum to only about 30 g WHO<sub>98</sub> TEQ<sub>P</sub>/year to air and  
30 20 g WHO<sub>98</sub> TEQ<sub>P</sub>/year to land. As discussed in Chapter 11, the surface soils in the United  
31 States are estimated to contain about 95 kg of PCB TEQs. Also, the release estimates may  
32 overestimate new releases because some portion may be passed through from inputs to outputs

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1 rather than new formation. Second, the new releases appear low compared to past releases  
2 associated with PCB production, use, and disposal. As discussed in Section 10.7, an estimated  
3 3,702 kg of WHO<sub>98</sub> TEQ<sub>P</sub> were released directly to the U.S. environment between 1930 and  
4 1977. Third, North American sediment studies have shown decreasing PCB levels since the  
5 1980s (Lebeuf et al., 1995; Cleverly et al., 1996), indicating that releases of newly formed PCBs  
6 are not large enough to prevent this decline. Accordingly, the original statement is still believed  
7 to likely be true, but it is acknowledged to be uncertain because releases could be estimated for  
8 only a few sources.

9

## 10 **10.2. RELEASES FROM COMMERCIAL PCB PRODUCTS**

### 11 **10.2.1. Approved PCB Disposal/Destruction Methods**

12 As discussed in the original report, landfilling and incineration can be used as disposal  
13 methods for PCBs. It is assumed that the amounts landfilled would not represent an  
14 environmental release. The incineration facilities achieve a high combustion efficiency, but  
15 some releases are possible. The original report summarizes TRI information on total PCB  
16 releases to air, surface water, and land. Insufficient information was available to convert these  
17 releases to TEQ estimates.

18

19

PCB Incineration
Releases
Not quantifiable.

20

21

### 22 **10.2.2. Releases of In-Service PCBs**

23 As discussed in the original report, insufficient information is available to make  
24 quantitative release estimates occurring from in-service PCBs. No changes were made to this  
25 conclusion, but some additional background information on accidental fires is provided below.  
26 Also, this section was expanded to include nonaccidental releases of in-service PCBs.

27 A variety of PCB products can remain in use for long time periods, such as paint, caulk,  
28 transformers, and capacitors. Releases from these products can occur via vaporization or leaks  
29 or during disposal operations. As discussed in the original report (see Section 10.6),  
30 approximately 568,000 MT of PCBs were used in the United States between 1930 and 1975. An

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1 estimated 50.3% were used in capacitors, and 26.8% were used in transformers. Assuming that  
2 these products contained an average of 8 mg WHO<sub>98</sub> TEQ<sub>P</sub>/kg (average concentration for  
3 Aroclor 1242, which accounted for over 50% of total sales—see Section 10.6 of original report),  
4 then a total of 3,500 kg of WHO<sub>98</sub> TEQ<sub>P</sub> were used in capacitors and transformers. It is  
5 unknown how much of this material is still in use today or what amount of releases may be  
6 occurring. Note that these products can be considered reservoirs because the releases can occur  
7 after their initial use, so they are also discussed in Chapter 11.

8 A report by the Environment Agency in the United Kingdom assessed the importance of  
9 releases of PCBs from various sources (Dyke, 2002). This report concluded that leaks from  
10 capacitors and transformers are likely to be the largest source of PCB releases occurring  
11 currently, although this is expected to decline as these devices are taken out of service and  
12 disposed. Leaks from electrical equipment were estimated to account for 80% of the total PCB  
13 releases occurring in the United Kingdom in 1998 (Dyke, 2002).

14 A number of PCB transformer fires have occurred in the United States, leading to PCB  
15 contamination of the interiors of office buildings (Michaud et al., 1994). Soot can be produced  
16 in large amounts, consisting of particles that may contain PCB concentrations up to  
17 5,000–8,000 mg/kg of soot (Michaud et al., 1994). The following are several examples of PCB  
18 fires in office buildings.

19 In the case of a transformer fire in the basement of the New York State office building in  
20 Binghamton, NY, the circulation of PCB-contaminated soot particles resulted in an average  
21 interior surface concentration of 162 mg/m<sup>2</sup> (expressed as the equivalent Aroclor 1254  
22 concentration) (Erickson, 1997). Additionally, the soot samples from the Binghamton PCB fire  
23 contained about 20 mg/g and 700 mg/g of total CDDs and total PCDFs, respectively (Erickson,  
24 1997). In 1985, a PCB transformer fire occurred in the basement transformer vault in the main  
25 building of the New Mexico State Highway Department Office Building (CDC, 1985). Interior  
26 air concentrations of PCBs in the transformer vault were found to average about 48 µg/m<sup>3</sup>.  
27 Surface wipes on horizontal surfaces had PCB concentrations ranging from 4,700 to  
28 30 million µg/m<sup>2</sup>. Other notable U.S. transformer fires include the office building at  
29 1 Marke Plaza in San Francisco in 1983, the Saniford Street office building in Boston in 1981,  
30 and the Page Belcher building in Tulsa (Michaud et al., 1994). In these fires, indoor air PCB  
31 concentrations ranged from 140 to 1,500 µg/m<sup>3</sup>; interior surfaces to the buildings ranged from

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1 20–90 µg/m<sup>2</sup> total PCBs. TCDF concentrations ranged from 4–30 pg/m<sup>3</sup> in the indoor office air  
2 and from 200–700 ng/m<sup>2</sup> to interior surfaces.

3  
4

Releases of In-Service PCBs
Releases
Not quantifiable.

5  
6

7 **10.3. CHEMICAL MANUFACTURING AND PROCESSING SOURCES**

8 The original report discussed Municipal Wastewater Treatment under Section 10.2. In  
9 this update, it has been moved to this section because these facilities are not associated with  
10 commercial PCB products and do conduct a type of chemical processing. Minor changes were  
11 made to the release estimates as summarized below.

12 For reference years 1987 and 1995, the concentration of dioxin-like PCBs that may be  
13 present in sewage sludge was estimated as 24.3 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg. This is based on the 1994  
14 survey of 74 plants as reported by Green et al. (1995) and Cramer et al. (1995). For reference  
15 year 2000, the concentration of dioxin-like PCBs that may be present in sewage sludge was  
16 estimated as 5.22 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg. This is based on the 2001 survey of 94 plants (U.S. EPA,  
17 2002d). The activity estimates were based on the 1988/1989 National Sewage Sludge Survey  
18 and the results of the 1984 to 1996 Clean Water Needs Surveys (U.S. EPA, 1999b). All  
19 beneficial uses were assumed to have the potential for release to the environment, resulting in  
20 increases in the product release estimates compared to the original report.

21 As discussed in EPA (2006), there is no clear evidence that other types of chemical  
22 manufacturing and processing facilities release dioxin-like PCBs.

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

24  
25  
26

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

1  
2

Municipal Wastewater Treatment	
Soil Releases	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> <li>• 1995—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> <li>• 2000—5.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—2.1 MMT of sludge.</li> <li>• 1995—3.2 MMT of sludge.</li> <li>• 2000—3.6 MMT of sludge.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—51 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 1995—78 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 2000—19 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> </ul>	
Product Releases	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> <li>• 1995—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> <li>• 2000—5.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge.</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.07 MMT of sludge.</li> <li>• 1995—0.5 MMT of sludge.</li> <li>• 2000—0.5 MMT of sludge.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—2 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 1995—12 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 2000—3 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> </ul>	

3  
4

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## 1 **10.4. COMBUSTION SOURCES**

### 2 **10.4.1. Municipal Waste Combustion**

3 The 2006 report concluded that insufficient information was available to develop  
4 quantitative release estimates from municipal waste incinerators. A number of additional studies  
5 are presented below that allow making preliminary estimates.

6 Dyke (2002) provides a review of PCB emission factors for municipal waste incinerators.  
7 These vary from 0.000027 to 14 ng TEQ<sub>P</sub>/kg. Dyke et al. (2003) provide a similar literature  
8 survey of 1990's data on incinerator emissions and fly ash concentrations of concurrently  
9 measured dioxin-like PCBs and CDD/CDF TEQ. Their literature summary supports the  
10 observation that WHO<sub>98</sub> TEQ<sub>P</sub> emission concentrations from MWCs are an order of magnitude  
11 and more lower than WHO<sub>98</sub> TEQ<sub>DF</sub>. They also provide some PCB emission factors from these  
12 references, showing a fairly wide range from as low as 0.0085 to as high as  
13 25.6 µg WHO<sub>98</sub> TEQ<sub>P</sub>/MT. Finally, they provide results of their own testing on two MWCs with  
14 different levels of pollution control. For one MWC, three of four tests were nondetect for all  
15 14 PCBs measured and the other test showed some positive concentrations. For the second  
16 MWC, two tests had positive measurements for PCB-114, PCB-118, PCB-123, and PCB-180.  
17 The range of reported WHO<sub>98</sub> TEQ<sub>P</sub> emission concentrations was between 0 (assuming ND = 0)  
18 and 0.016 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> (assuming ND = QL).

19 Sakai et al. (1999) found that the input of coplanar PCBs into the municipal solid waste  
20 incineration facilities in Kyoto City (Japan) was 0.13–0.29 mg-TEQ per ton waste, the total  
21 output of coplanar PCBs (the sum released from emission gas, fly ash, and bottom ash) was 4.9  
22 mg TEQ per ton waste. The PCB emission factor for gas releases was reported to be 1.2 µg  
23 TEQ/ton of waste burned. They reported PCB concentrations in fly ash of 0.053 ng TEQ/g and in  
24 bottom ash as 0.000023 ng TEQ/g.

25 CDD/CDFs and dioxin-like PCBs were measured in the emissions from an MWC in  
26 Madrid, Spain, which was equipped with a high level of pollution control (Abad et al., 2006).  
27 Over 16 samples, CDD/CDF emissions averaged 0.047 ng I-TEQ/Nm<sup>3</sup>, and dioxin-like PCBs  
28 added an average of 0.0015 ng I-TEQ/Nm<sup>3</sup>, with most of this dioxin-like PCB contribution from  
29 PCB-126.

30 Eight incinerators, including two commercial MWCs, were sampled for CDD/CDFs,  
31 PCBs, and HCB in a study conducted in Japan (Kim et al., 2004a). The average concentration

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1 over all eight incinerators was 0.281 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup> for CDD/CDFs and  
2 0.023 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> for PCBs, suggesting a factor of difference of 10 on average. The  
3 disparity from one of the two MWC incinerators was 0.069 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup> for  
4 CDD/CDF and 0.009 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> for PCBs. Emissions were much lower for the other  
5 MWC, with reported TEQ concentrations uninformative at 0.000 ng WHO<sub>98</sub> TEQ<sub>DFP</sub>/Nm<sup>3</sup>.

6 Francois et al. (2005) provide side-by-side measurements of CDD/CDFs and dioxin-like  
7 PCBs, which contradict the observations provided by Dyke et al. (2003). Francois et al. (2005)  
8 reports on testing at 15 incinerators including three MWCs in Belgium. The dioxin-like PCBs  
9 often dominated the overall TEQ emissions. For example, the average shares of the dioxin-like  
10 PCBs to total TEQ were 22, 34, and 97% for the three MWCs. The stack concentrations of  
11 dioxin-like PCBs were 0.0008, 0.045, and 0.0034 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, compared to  
12 corresponding CDD/CDF concentrations of 0.0014, 0.0014, and 0.012 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup>.  
13 Based on these concentrations and other plant characteristics, annual dioxin-like PCB emissions  
14 were quantified in all of these plants at 0.4, 7.0, and 1.2 mg WHO<sub>98</sub> TEQ<sub>P</sub>/year.

15 Kim et al. (2005) measured 209 congeners in stack emissions from nine facilities in  
16 Japan, including three MWCs. They did not measure CDD/CDFs, but their measured  
17 concentrations can be compared with other studies identified above. They detected PCBs at all  
18 facilities, with total PCBs ranging from 10–700 ng/Nm<sup>3</sup> and coplanar PCBs in the range of  
19 1–25 ng/Nm<sup>3</sup> (0.008–0.324 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>). On a class basis, the average from the  
20 MWCs was the highest at 0.136 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>.

21 The PCB emission factor for municipal waste incinerators was assumed to equal the  
22 geometric mean of the range reported by Dyke et al., 2003 (0.0085 to  
23 25.6 µg WHO<sub>98</sub> TEQ<sub>P</sub>/MT) which is 0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg. This emission factor is considered  
24 preliminary due to the inconsistency in the results. The activity data are presented in Chapter 3.  
25 PCBs are also likely to be present in the ash, but these would be landfilled and not considered an  
26 environmental release. The inventory decision criteria and releases to all media are summarized  
27 below:

<b>Inventory Decision Criteria for Municipal Waste Combustion</b>	
	<b>Air Water Solids Products</b>
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

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<b>Municipal Waste Combustion</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 1995—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 2000—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—13.7 billion kg.</li> <li>• 1995—29.8 billion kg.</li> <li>• 2000—29.4 billion kg.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—7 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—15 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—15 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>	

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#### **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.

<b>Industrial Wood Combustion</b>
<b>Releases</b>
Not quantifiable.

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1 **10.4.3. Medical Waste Incineration**

2 EPA (2006) concluded that insufficient evidence existed to derive emission factors for  
3 PCB releases from medical waste combustion. As discussed below, additional studies were  
4 found that allowed making preliminary release estimates.

5 Dyke et al. (2003) surveyed the literature for studies providing measurements of  
6 dioxin-like PCBs along with CDD/CDFs from power stations and waste incineration processes.  
7 They identified a study published in 1996 (Ehrlich et al., 1996) in which the PCB emission  
8 concentration from a medical waste incineration was 0.035 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, while it was  
9 0.97 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup> for CDD/CDFs. They also conducted their own measurements on a  
10 medical waste incinerator in the United Kingdom. They quantified concentrations of PCB-118,  
11 PCB-123, PCB-170, and PCB-180—but not the other 14 congeners. Assuming ND = 0, one of  
12 two runs had a concentration of 0.00007 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, while the other had a  
13 concentration of 0.022 WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> at ND = 0. In contrast, the same two runs had  
14 CDD/CDF concentrations at ND = 0 at 0.07 and 0.05 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup>.

15 The data reported by Dyke et al. (2003) suggest that PCB TEQ emissions are 1 to 25% of  
16 the dioxin emissions. The Ehrlich et al. (1996) data suggest that the PCB TEQ emissions are 4%  
17 of the dioxin emissions. The Ehrlich et al. (1996) value was selected as a central estimate and  
18 multiplied by the average CDD/CDF emission factor for each reference year (total CDD/CDF  
19 emissions divided by the total activity as reported in Chapter 3). This procedure gave the  
20 emission factors shown below. These emission factors are considered preliminary because the  
21 studies provided insufficient information to directly derive them. The activity data are presented  
22 in Chapter 3. PCBs are also likely to be present in the ash, but these would be landfilled and not  
23 considered an environmental release. The inventory decision criteria and releases to all media  
24 are summarized below:

<b>Inventory Decision Criteria for Medical Waste Incineration</b>	
	<b>Air Water Solids Products</b>
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

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<b>Medical Waste Incineration</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—68 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 1995—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 2000—24 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—1.43 billion kg.</li> <li>• 1995—0.77 billion kg.</li> <li>• 2000—0.6 billion kg.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—97 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—18 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—14 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>	

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#### 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.

<b>Tire Combustion</b>
<b>Releases</b>
Not quantifiable.

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1 **10.4.5. Cigarette Smoking**

2 As discussed in the original report, PCB releases can occur during cigarette  
 3 smoking. No changes were made to these estimates as summarized below.

4 A preliminary estimate of potential emissions of dioxin-like PCBs can be made using the  
 5 following assumptions: (a) the average WHO<sub>98</sub> TEQ<sub>P</sub> content of seven brands of U.S. cigarettes  
 6 reported by Matsueda et al. (1994), 0.64 pg/pack (0.032 pg/cigarette), is representative of  
 7 cigarettes smoked in the United States; (b) dioxin-like PCBs are neither formed nor destroyed,  
 8 and the congener profile reported by Matsueda et al. (1994) is not altered during combustion of  
 9 cigarettes; and (c) all dioxin-like PCBs contributing to the TEQ are released from the tobacco  
 10 during smoking. This emission factor is considered preliminary because of the multiple  
 11 assumptions required in its derivation. Cigarette consumption is discussed in Section 5.5.

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

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<b>Inventory Decision Criteria for Cigarette Smoking</b>	
	<b>Air Water Solids Products</b>
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

<b>Cigarette Smoking</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.03 pg WHO<sub>98</sub> TEQ<sub>P</sub>/cigarette (Preliminary).</li> <li>• 1995—0.03 pg WHO<sub>98</sub> TEQ<sub>P</sub>/cigarette (Preliminary).</li> <li>• 2000—0.03 pg WHO<sub>98</sub> TEQ<sub>P</sub>/cigarette (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—575 billion cigarettes.</li> <li>• 1995—487 billion cigarettes.</li> <li>• 2000—440 billion cigarettes.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—&lt;0.1 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>	

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#### **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<sup>3</sup> 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:

<b>Inventory Decision Criteria for Sewage Sludge Incineration</b>	
	<b>Air Water Solids Products</b>
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

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<b>Sewage Sludge Incineration</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<ul style="list-style-type: none"> <li>• 1987—0.51 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge (Preliminary).</li> <li>• 1995—0.51 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge (Preliminary).</li> <li>• 2000—0.51 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sludge (Preliminary).</li> </ul>	
<b>Activity Levels</b>	
<ul style="list-style-type: none"> <li>• 1987—0.865 MMT.</li> <li>• 1995—2.11 MMT.</li> <li>• 2000—1.42 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—0.4 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—1 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—0.7 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>	

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#### 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

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1 mix of garden waste and polyvinyl chloride (PVC) waste had the highest emission factor of  
 2 190 ng PCB TEQ/kg burned. The other tests ranged from 0.3 to 3.2 ng WHO<sub>98</sub> TEQ<sub>p</sub>/kg burned.  
 3 The dioxin-like PCBs generally made up much less than 10% of the total TEQ emissions.

4 As reported in EPA (2006), Lemieux (1997) also measured PCB emissions from tests  
 5 simulating backyard barrel burning. The average emission factor across two tests was  
 6 5.26 ng WHO<sub>98</sub> TEQ<sub>p</sub>/kg waste burned. This emission factor was selected as the most  
 7 representative of typical domestic waste.

8 Lemieux (1997) also collected ash samples from open barrel burning and analyzed for  
 9 PCBs. Ash samples from the experiments were combined, resulting in two composite  
 10 samples—one for recyclers and one for nonrecyclers (see Table 10-2). The overall average was  
 11 0.8 ng WHO<sub>98</sub> TEQ<sub>p</sub>/kg of ash.

12 The activity levels for backyard barrel burning (total waste burned and ash generated)  
 13 were presented in Section 6.5.2.

14 The inventory decision criteria and releases to all media are summarized below:  
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<b>Inventory Decision Criteria for Backyard Barrel Burning</b>			
	<b>Air</b>	<b>Water</b>	<b>Solids Products</b>
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

<b>Backyard Barrel Burning</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—5.3 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of waste burned.</li> <li>• 1995—5.3 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of waste burned.</li> <li>• 2000—5.3 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of waste burned.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—7.87 MMT.</li> <li>• 1995—8.18 MMT.</li> <li>• 2000—6.49 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—41 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 1995—43 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 2000—34 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> </ul>
<b>Solid Residue Releases</b>	
<b>Emission Factors</b>	<ul style="list-style-type: none"> <li>• 1987—0.8 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of ash.</li> <li>• 1995—0.8 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of ash.</li> <li>• 2000—0.8 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of ash burned.</li> </ul>
<b>Activity Levels</b>	<ul style="list-style-type: none"> <li>• 1987—1.2 MMT.</li> <li>• 1995—1.2 MMT.</li> <li>• 2000—0.97 MMT.</li> </ul>
<b>Releases</b>	<ul style="list-style-type: none"> <li>• 1987—1 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 1995—1 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> <li>• 2000—0.8 g WHO<sub>98</sub> TEQ<sub>P</sub>.</li> </ul>

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#### **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.

<b>Petroleum Refining Catalyst Regeneration</b>	
<b>Air Releases</b>	
Not quantifiable.	

1 **10.4.9. Hazardous Waste Incineration**

2 This is a completely new section on hazardous waste incineration.

3 Two studies were identified from outside of the United States that measured emissions of  
4 dioxin-like PCBs along with dioxins and furans from hazardous waste incinerators. One of the  
5 studies was consistent with studies on municipal solid waste incinerators, which showed  
6 CDD/CDF TEQ emissions to be an order of magnitude and more higher than PCB emissions.  
7 Kim et al. (2005) measured 209 congeners in stack emissions from nine facilities, which  
8 included two industrial waste incinerators and a “specific industrial waste incinerator.” The  
9 emission concentrations of the dioxin-like PCBs in the industrial waste incinerators were  
10 0.136 for the “specific” incinerator and 0.025 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> for the average of the  
11 two industrial waste incinerators. These were characterized as being equal to 2.9 and 1.3% of  
12 the emission concentrations of WHO<sub>98</sub> TEQ<sub>DF</sub>. On the other hand, Francois et al. (2005)  
13 measured dioxins, furans, and coplanar PCBs from 15 facilities including one HWI. The  
14 concentration of the PCBs was 0.0051 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, which was almost three times  
15 higher than the measurement of CDD/CDFs, at 0.0019 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>. The annual  
16 emission of dioxin-like PCBs from this facility was estimated at 1.5 mg WHO<sub>98</sub> TEQ<sub>P</sub>/year.  
17 Given the inconsistent results from these two studies, it is unclear how to make emission  
18 estimates on even a preliminary basis.

19 Therefore, the available data were judged inadequate to support development of a  
20 quantitative estimate of a dioxin-like PCB emission factor for this source category.

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Hazardous Waste Incineration
Releases
Not quantifiable.

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**10.4.10. Power Plants**

26 This is a completely new section.

27 Emissions from power plants were estimated to account for 2% of the total PCB releases  
28 occurring in the United Kingdom in 1998 (Dyke, 2002).

29 Brodsky et al. (2003) reported on measurements from six combustion sources in Russia,  
30 including two power plants. Numerous individual congener concentrations in the stack gas

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1 emissions were provided including some dioxin-like PCBs, although no TEQ estimates were  
2 provided and no congener-specific emission factors were provided. Concentrations were  
3 provided for PCB-105, PCB-118, PCB-123, PCB-156, PCB-157, PCB-170, and PCB-180. The  
4 TEQ concentration in the power plant for these congeners was 0.02 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>.

5 Francois et al. (2005) reported on testing at 15 incinerators including one coal-fired  
6 power plant. They measured emissions of CDD/CDF and PCB as  
7 0.0003 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup> and 0.0009 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, respectively. Extrapolating to  
8 annual emissions, they estimated an emission of 1.17 mg WHO<sub>98</sub> TEQ<sub>P</sub>/year. Dyke et al. (2003)  
9 reported on emission measurements from a coal-fired power station in the United Kingdom.  
10 They found nondetects for all dioxin-like PCBs tested, except a positive for PCB-180 in one of  
11 two tests.

12 The available data were judged inadequate to support development of a quantitative  
13 estimate of a dioxin-like PCB emission factor for this source category.

Power Plants
Releases
Not quantifiable.

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#### 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<sup>3</sup>. 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<sub>DF</sub>/kg burned (the low for the test  
close to the blank) to 26 ng I-TEQ<sub>DF</sub>/kg. The TEF scheme used to characterize PCB emissions  
was not clear but assumed here to be WHO<sub>98</sub>. This implies that the PCB emission factor ranged  
from 0.06 to 1.6 WHO<sub>98</sub> TEQ<sub>P</sub>.

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1 For the purposes of deriving a preliminary estimate, it is assumed that the PCB TEQ  
 2 emission factor is 6% of the one for CDD/CDFs (based on the results from Collet and Fianni  
 3 [2006]). As discussed in Chapter 6, the forest fire emission factor is 3 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg.  
 4 This is adjusted to 0.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg for PCBs. This emission factor is considered  
 5 preliminary because it is uncertain how well the limited testing represents all fire/wood types.  
 6 The activity levels for forest fires are presented in Chapter 6. PCBs are also likely to be present  
 7 in the ash, but insufficient information was available to make quantifiable estimates.

8 The inventory decision criteria and releases to all media are summarized below:  
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<b>Inventory Decision Criteria for Forest Fires</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

<b>Forest Fires</b>
<b>Air Releases</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—0.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 1995—0.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 2000—0.2 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—61 MMT.</li> <li>• 1995—55 MMT.</li> <li>• 2000—243.8 MMT.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—12 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—11 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—49 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>
<b>Solid Residue Releases</b>
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<sup>3</sup> and coplanar PCBs in the range of 1–25 ng/Nm<sup>3</sup> (0.008–0.324 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>). The three metal facilities had these results: aluminum smelting furnace—0.020 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>; copper smelting furnace—0.026 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>; and sintering furnace—0.018 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>. 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<sup>3</sup>, followed by 105 at 2–4 ng/Nm<sup>3</sup>, and 77 at 2–3 ng/Nm<sup>3</sup>, with others detected at below 2 ng/Nm<sup>3</sup>. On a TEQ basis, including CDD/CDFs and dioxin-like PCBs (the authors calculated CDD/CDF

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1 using I-TEFs while dioxin-like PCB TEQ was calculated using WHO<sub>98</sub> TEFs), the PCBs  
2 contributed less than 10% of the total TEQ concentration, which averaged between 0.6 and  
3 1.6 ng total TEQ/Nm<sup>3</sup>. The mass emissions of total TEQ from the three plants, calculated based  
4 on emission concentrations in conjunction with mass loadings, totaled 8.7, 9.2, and  
5 10.9 g TEQ/year over the three plants.

6 Kim et al. (2004a) reported on the testing of eight incinerators including two sintering  
7 furnaces and four smelting furnaces for CDD/CDFs, PCBs, and HCB. The average over all  
8 eight incinerators, on a WHO<sub>98</sub> TEQ basis, was 0.281 ng/Nm<sup>3</sup> for CDD/CDFs and 0.023 ng/Nm<sup>3</sup>  
9 for PCBs, suggesting a factor of 10 difference on average. The aluminum nonferrous metal  
10 smelter showed a PCB TEQ concentration at 0.016 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, which was only  
11 one-half that of CDD/CDF TEQ, not the order of magnitude suggested by averaging all  
12 eight facilities. The copper smelter had the same TEQ concentration for both PCBs and  
13 CDD/CDFs: 0.002 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>. The most informative tests, perhaps, were the  
14 two iron ferrous metal smelters, where CDD/CDF overwhelmed PCB emissions. The CDD/CDF  
15 emission concentrations were 1.492 and 0.926 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup>, while the PCB emission  
16 concentrations were 0.112 and 0.067 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>, respectively.

17 Brodsky et al. (2003) reported on measurements from six combustion sources in Russia,  
18 including a nonferrous metallurgy plant, a cement plant, an aluminum plant in the calcination  
19 furnace, and an aluminum plant in the entry into the electrostatic filter. Numerous individual  
20 congener concentrations in the stack gas emissions were provided including some dioxin-like  
21 PCBs, although no TEQ estimates were provided and no congener-specific emission factors were  
22 provided. Concentrations were provided for PCB-105, PCB-118, PCB-123, PCB-156, PCB-157,  
23 PCB-170, and PCB-180. The TEQ concentration in these four facilities ranged from 0.001 to  
24 0.006 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>. Brodsky et al. (2003) provided a total concentration (sum of all  
25 congeners) and an emission factor of total PCBs in µg/MT.

26 Fisher et al. (2004) reported on tests for an experimental sinter box apparatus, which is  
27 essentially a small pilot plant. A raw mix of typical iron ore feed—including iron ore fines,  
28 fluxes, fuel in the form of coke, and some recycled materials—was combined with five different  
29 amounts of potassium chloride to test the effect of chloride on CDD/CDF and dioxin-like PCB  
30 emissions. A correlation was found for both CDD/CDF and dioxin-like PCB emissions with  
31 chloride content. At a chloride concentration in the entire feed of 250 mg/kg and less, which

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1 encompassed a baseline run and a run at 250 mg/kg chloride, CDD/CDF emissions were fairly  
2 steady, suggesting chloride did not affect emissions at concentrations in this range, but at higher  
3 concentrations with up to about 800 mg/kg chloride added, the effect was second order. For  
4 PCBs, the effect was more linear—a linear rise in PCB emissions was noted with increasing  
5 chloride content. PCDF concentrations dominated CDD/CDF, and on a TEQ basis, CDD/CDF  
6 dominated over PCBs. Specifically, the ratio of PCB to CDD/CDF TEQ concentrations was in  
7 the range of 0.07 for the five tests. On a TEQ basis, PCB-126 contributed 90–95% of total PCB  
8 TEQ, but PCB-105 and PCB-118 contributed the most on a straight concentration basis. The  
9 authors concluded that at typical chloride concentrations of 50–100 mg/kg in the industry, the  
10 total CDD/CDF/PCB concentrations are expected to be below 1.5 ng TEQ/Nm<sup>3</sup>.

11 Francois et al. (2004) measured emissions at 15 facilities, including two metal smelters  
12 and an iron ore sintering plant. For most facilities, their sampling indicated that the TEQ  
13 emissions of dioxin-like PCBs nearly matched that of dioxins. With the iron ore sintering plant,  
14 however, the dioxin-like PCBs were an order of magnitude less than dioxins:  
15 0.058 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup> versus 0.65 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/Nm<sup>3</sup>. For the aluminum and copper  
16 smelters, PCB emissions were a factor of 2 (at 0.046 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>) and a factor of 4 (at  
17 0.017 ng WHO<sub>98</sub> TEQ<sub>P</sub>/Nm<sup>3</sup>) less than dioxin TEQ, respectively. They calculated total annual  
18 TEQ emissions for these plants and estimated dioxin-like PCB emissions to be 2.3 and  
19 18.8 mg WHO<sub>98</sub> TEQ<sub>P</sub>/year for the aluminum and copper smelters, respectively, and to be much  
20 higher at 474 mg WHO<sub>98</sub> TEQ<sub>P</sub>/year for the iron ore sintering plant.

21 As described above, several studies outside of the United States have measured  
22 dioxin-like PCBs along with CDD/CDFs from a variety of metal processing facilities including  
23 ferrous and nonferrous smelters, iron ore sintering facilities, and other combustion units within  
24 the metal refining industry. These studies did not report emission factors but the concentration  
25 data consistently suggest that emissions from iron ore sintering plants are about an order of  
26 magnitude or more lower than CDD/CDFs, on a TEQ basis. Accordingly, for the purposes of a  
27 preliminary estimate, the PCB emission factor is assumed to be 10% of the CDD/CDF emission  
28 factor. The activity levels (from Chapter 7) and release estimates are shown below. The studies  
29 also indicate that PCB emissions are occurring from copper and aluminum smelting operations,  
30

1 but the results are not consistent and not easily converted to TEQ emission factors. Thus,  
 2 quantitative estimates could not be made for these facilities.

3 The inventory decision criteria and releases to all media are summarized below:  
 4

<b>Inventory Decision Criteria for Iron Ore Sinter Production</b>	
	<b>Air Water Solids Products</b>
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

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<b>Iron Ore Sinter Production</b>	
<b>Air Releases</b>	
<b>Emission Factors</b>	
<i><b>Wet Scrubber</b></i>	
<ul style="list-style-type: none"> <li>• 1987—0.06 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> <li>• 1995—0.06 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> <li>• 2000—0.06 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> </ul>	
<i><b>Fabric Filter</b></i>	
<ul style="list-style-type: none"> <li>• 1987—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> <li>• 1995—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> <li>• 2000—0.5 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg of sinter (Preliminary).</li> </ul>	
<b>Activity Levels<sup>a</sup></b>	
<ul style="list-style-type: none"> <li>• 1987—14.5 MMT.</li> <li>• 1995—12.4 MMT.</li> <li>• 2000—10.6 MMT.</li> </ul>	
<b>Releases</b>	
<ul style="list-style-type: none"> <li>• 1987—4 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—3 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—3 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>	

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<sup>a</sup>Fifty-nine percent of sinter production was at facilities with wet scrubbers, and 41% was at facilities with fabric filters.

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<b>Copper and Aluminum Smelting</b>
<b>Air Releases</b>
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<sub>98</sub> TEQ<sub>P</sub>.





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**Table 10 1. Summary of PCB releases for reference years 1987, 1995, and 2000 (g WHO<sub>98</sub> TEQ<sub>P</sub>/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
<b>Metal refining</b>												
Iron ore sintering												
1987		4										
1995		3										
2000		3										
Copper smelting			x									
Aluminum smelting			x									
<b>Total</b>												
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.

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**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 <sub>98</sub> TEQ <sub>P</sub>		0.0009	0.0006	0.0008

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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).

1           **11. RESERVOIR SOURCES OF CDD/CDFS AND DIOXIN-LIKE PCBs**  
2  
3

4           This introduction has been expanded to more clearly define reservoirs. Chapters 2  
5 through 10 of this document discuss sources with the potential for initial releases of dioxin-like  
6 compounds to the environment in the United States. This chapter addresses releases from  
7 reservoirs that are defined as materials or places that contain previously released CDD/CDFs or  
8 dioxin-like PCBs and have the potential for redistributing these compounds into the environment.  
9 Potential reservoirs include soils, sediments, biota, water, and some products. Products that  
10 contain CDD/CDFs can be considered reservoirs when they have the potential for releases after  
11 their initial use. The atmosphere could be considered a reservoir but is excluded here because it  
12 is the primary medium for transporting and distributing CDDs and CDFs over large geographical  
13 areas. Thus, it is considered a temporary holding place rather than a long-term reservoir.  
14 Although water is also an important transport medium, the residence times can be long, and,  
15 therefore, it is appropriately considered a reservoir.

16           The definition of reservoirs as used in this document also excludes CDD/CDFs contained  
17 in natural ball clay deposits. The CDD/CDFs contained in ball clay were formed by geochemical  
18 processes that are thought to have occurred millions of years ago. Any release from ball clay  
19 would be an initial release to the contemporary environment, and, therefore, ball clay is not  
20 considered to be a reservoir. Potential ball clay releases are covered in Chapter 9 on Natural  
21 Sources.

22           Soils in some locations could have elevated CDD/CDF levels due to past activities such  
23 as pesticide use, spills, illegal disposal, or fires. These areas would be considered part of the soil  
24 reservoir and would have the potential for greater release rates than normal soils with background  
25 CDD/CDF levels. The soil-release estimates presented in this document do not include releases  
26 from these “hot spots” due to lack of appropriate information. However, they could be important  
27 events on a local scale and should be considered where feasible.

28           Dioxin-like compounds are sequestered by a reservoir only until physical processes  
29 cause these contaminants to become released into the open environment over a defined time and  
30 space. When this occurs, reservoirs become sources of dioxin-like compounds in the circulating  
31 environment. Figure 11-1 presents a conceptual diagram of flux and exchange of dioxin-like  
32 compounds to multiple environmental compartments such as soils, water, air, sediments, and

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1 biota. This dynamic system consists of fluxes in and out of the atmosphere as well as other  
2 exchanges between reservoirs and the atmosphere (recall that the atmosphere is not defined here  
3 as an environmental reservoir, rather as a transport medium for dioxin-like compounds).  
4 Movement of dioxin-like compounds between media can be induced by the physical processes of  
5 volatilization, wet and dry atmospheric particle and vapor deposition, adsorption, erosion and  
6 runoff, resuspension of soils into air, and resuspension of sediments into water.

7 This chapter describes the major reservoir sources of CDD/CDFs and PCBs, including, to  
8 the extent feasible, estimates of the potential mass of CDD/CDFs and PCBs in each reservoir, the  
9 chemical/physical mechanisms responsible for releases of these compounds, and estimates of  
10 potential annual releases from each reservoir.

### 11 12 **11.1. SOIL RESERVOIRS (ORIGINALLY SECTION 11.2.1)**

13 This section provides revised estimates of the amounts of CDD/CDFs in soil reservoirs.

14 Harrad and Jones (1992) and Duarte-Davidson et al. (1997) estimated the CDD/CDF  
15 content of soils in the United Kingdom by multiplying the soil surface area by the contamination  
16 depth, soil density, and CDD/CDF concentration in the soil. A similar approach was used here  
17 to estimate the amount CDD/CDFs in surface soils of the United States. The following inputs  
18 were used in these calculations:

- 19  
20 • Surface soils were divided into rural and urban areas to reflect differences in the  
21 CDD/CDF levels. Urban areas were assumed to have an average concentration of  
22 10 pg WHO TEQ<sub>DF</sub>/g, and rural soils, 2 pg WHO TEQ<sub>DF</sub>/g (U.S. EPA, 2007b).
- 23 • The urban land area in the United States is 1.82 million km<sup>2</sup> based on Census Bureau  
24 statistics for metropolitan areas (USDA, 2002). The portion of urban areas covered by  
25 impervious surfaces (rather than soil) varies widely. For the purposes of a preliminary  
26 estimate, it was assumed that an average of 50% of the metropolitan land area had soil  
27 coverage. The land area of nonmetropolitan areas in the United States is  
28 7.28 million km<sup>2</sup> (USDA, 2002).
- 29 • The soil density was assumed to be 2.6 g/cm<sup>3</sup> (Brady, 1984).
- 30 • The contamination depth was assumed to be 10 cm (U.S. EPA, 2007b).

31  
32 Based on these assumptions, the amount of CDD/CDFs in U.S. surface soils was estimated as  
33 2,370 kg WHO TEQ<sub>DF</sub> in urban soils and 3,790 kg WHO TEQ<sub>DF</sub> in rural soils, for a total of

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1 6,150 kg WHO TEQ<sub>DF</sub>. EPA (2007b) found that average PCB TEQs were about 4% of average  
2 total D/F/P TEQs in rural soils. Assuming this percentage applies to urban areas as well, this  
3 would imply that the soil reservoir contains about 95 kg WHO TEQ<sub>P</sub>. These calculations are not  
4 definitive and only indicate approximate amounts of dioxins that may be contained in U.S.  
5 surface soils.

6 Soils in some locations could have elevated CDD/CDF levels (or “hot spots”) due to  
7 uncontrolled activities such as spills, illegal disposal, or fires. Elevated soil levels could also  
8 occur in areas where 2,4-D and 2,4,5-T were used and areas with land-applied sludges/ash.  
9 These areas would be considered part of the soil reservoir and would have the potential for  
10 greater release rates than normal soils with background CDD/CDF levels. The amounts in  
11 landfills could also be considered part of the soil reservoir, although the potential for release is  
12 much less. No estimates could be made for the additional CDD/CDF soil burdens due to the  
13 uncontrolled activities, but estimates were made for the other activities as discussed below.

14 Estimates can be made for the total mass of CDD/CDF TEQs that have been applied to  
15 soil from past use of the pesticides 2,4-dichlorophenoxyacetic acid (2,4-D) and  
16 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). As discussed in Chapter 11 of the original report,  
17 the total amounts of CDD/CDF released to the environment are as follows:

18

- 19 • From 2,4-D use during the period of 1975 to 1995, the total release was estimated as  
20 0.55 kg WHO<sub>98</sub> TEQ<sub>DF</sub> (0.35 kg I-TEQ<sub>DF</sub>).
- 21 • From 2,4,5-T use over the period of 1950 to 1979, the total release was estimated as  
22 36 kg of 2,3,7,8-TCDD.  
23

24 The amounts of CDD/CDFs in landfills can also be considered a soil reservoir with the  
25 potential for releases in the future. The earlier chapters provided estimates of the amounts of  
26 CDD/CDFs landfilled for many sources. As shown in Table 11-1, the total amounts landfilled  
27 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  
28 assumed that most landfills operate for 30 years and the average annual input equals the average  
29 over the reference years (2,040 g TEQ), then the cumulative sum would be 61,000 g TEQ. This  
30 should be regarded as a preliminary estimate because it is based on numerous assumptions and  
31 limited data.

1 A variety of waste types containing CDD/CDFs are land applied such as sewage sludge,  
2 wood pulp sludge, residential wood burning ash, and beneficial uses of cement kiln clinker.  
3 These sources also contribute to the soil reservoir. As shown in Table 1-9, these sum to  
4 2,400 g TEQ in 1987, 2,500 g TEQ in 1995, and 2,300 g TEQ in 2000. If it is assumed that  
5 operations persist for 30 years and the average annual input equals the average over the reference  
6 years (2,400 g TEQ), then the cumulative sum would be 72,000 g TEQ. This should be regarded  
7 as a preliminary estimate because it is based on numerous assumptions and limited data.

8 In summary, the total mass of CDD/CDF that is contained in the soil reservoir is  
9 approximately 6,150 kg WHO<sub>98</sub> TEQ with perhaps an additional 170 kg TEQ from past  
10 additions (landfills - 61 kg TEQ, pesticide use - 37 kg TEQ and land-applied sludges/ash - 72 kg  
11 TEQ). As discussed below, various forms of degradation/removal can occur in soil, which  
12 would reduce these contributions from the past, making it uncertain how much of these remain in  
13 the soil reservoir today.

#### 14 15 **11.1.1. Mechanisms Responsible for Releases from Surface Soils**

16 As discussed in the original report, a number of studies have demonstrated that soil  
17 releases can occur via erosion, degradation, volatilization, and particle resuspension.

#### 18 **11.1.2. Estimated Annual Releases from Soil to Water**

19 Nonpoint sources of CDD/CDFs to waterways include stormwater runoff from urban  
20 areas and soil erosion in rural areas during storms. Approaches for estimating national loadings  
21 to water for both of these sources are described below.

##### 22 23 **11.1.2.1. Urban Runoff**

24 No changes were made in this update. As discussed in the original report, a wide range  
25 of CDD/CDF concentrations were measured in urban runoff at 23 sites in California (Mathur  
26 et al., 1997; Fisher et al., 1999). The midpoint of the 4 order of magnitude range was selected.  
27 Based on the wide range of results and uncertainty about the representativeness of the samples,  
28 this factor is considered preliminary. The run-off volume was calculated based on rainfall data  
29 and urban area data. All factors and release estimates are presented in the release summary  
30 below.

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**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<sub>98</sub> TEQ<sub>DF</sub>/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<sub>98</sub> TEQ<sub>P</sub>/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<sub>98</sub> TEQ<sub>DF</sub> for 1987, 1995, and 2000, respectively. Similarly, the PCB release estimates were calculated as 200, 180, and 170 g WHO<sub>98</sub> TEQ<sub>P</sub> 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:

<b>Inventory Decision Criteria for Soil Reservoirs</b>				
	<b>Air</b>	<b>Water</b>	<b>Solids</b>	<b>Products</b>
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			

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<b>Soil Reservoirs</b>
<b>Releases to Air</b>
Not quantifiable.
<b>Releases to Urban Water</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—1 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (1 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> <li>• 1995—1 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (1 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> <li>• 2000—1 pg WHO<sub>98</sub> TEQ<sub>DF</sub>/L (1 pg I-TEQ<sub>DF</sub>/L) (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—<math>1.24 \times 10^{14}</math> L/yr.</li> <li>• 1995—<math>1.33 \times 10^{14}</math> L/yr.</li> <li>• 2000—<math>1.42 \times 10^{14}</math> L/yr.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—120 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 1995—130 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) (Preliminary).</li> <li>• 2000—140 g (WHO<sub>98</sub> TEQ<sub>DF</sub> or I-TEQ<sub>DF</sub>) (Preliminary).</li> </ul>
<b>Release to Rural Water</b>
<b>Emission Factors</b> <ul style="list-style-type: none"> <li>• 1987—1.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary) and 0.07 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 1995—1.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary) and 0.07 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> <li>• 2000—1.7 ng WHO<sub>98</sub> TEQ<sub>DF</sub>/kg (Preliminary) and 0.07 ng WHO<sub>98</sub> TEQ<sub>P</sub>/kg (Preliminary).</li> </ul>
<b>Activity Levels</b> <ul style="list-style-type: none"> <li>• 1987—2.91 billion MT of soil.</li> <li>• 1995—2.62 billion MT of soil.</li> <li>• 2000—2.46 billion MT of soil.</li> </ul>
<b>Releases</b> <ul style="list-style-type: none"> <li>• 1987—4,900 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary) and 200 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 1995—4,500 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary) and 180 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> <li>• 2000—4,200 g WHO<sub>98</sub> TEQ<sub>DF</sub> (Preliminary) and 170 g WHO<sub>98</sub> TEQ<sub>P</sub> (Preliminary).</li> </ul>

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### 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.

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<b>Water Reservoirs</b>
<b>Releases to Air</b>
Not quantifiable.
<b>Releases to Sediment</b>
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<sub>98</sub> TEQ<sub>DF</sub> (120 kg I-TEQ<sub>DF</sub>) 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.

<b>Sediment Reservoirs</b>
<b>Releases to Water</b>
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.

1 **11.4.1. Mechanisms Responsible for Supply to and Releases from Biota**

2 The original report identified vapor absorption and desorption as an important  
3 mechanism for plants and ingestion/bioaccumulation as an important mechanism for animals.  
4

5 **11.4.2. Approaches for Measuring and Estimating Releases from Biota**

6 The original report describes a number of studies that evaluate the CDD/CDF releases  
7 from biota to soil and air, but insufficient information is available to make quantitative estimates  
8 for national releases.  
9

<b>Biota Reservoirs</b>
<b>Releases to Air</b>
Not quantifiable.
<b>Releases to Soil</b>
Not quantifiable.

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12 **11.5. PRODUCT RESERVOIRS**

13 This is a new section. As discussed in Chapter 8, a number of chemical products contain  
14 CDD/CDFs. Some of these can be considered reservoirs because they have the potential for  
15 CDD/CDF releases after their initial use. Others are used in a manner such that any releases  
16 would occur during their initial use, and therefore, they are not considered a reservoir for future  
17 releases. For example, 2,4-D is a pesticide that is applied to foliage and would have an  
18 immediate release to biota and soil. Although it may persist in the environment after application,  
19 it would become part of the biota or soil reservoir rather than a separate product reservoir.  
20 Similarly, chlorobenzenes are used as pesticides or chemical intermediates for pesticides and,  
21 therefore, are not considered product reservoirs. The products that may represent potential  
22 reservoirs are discussed below.  
23

24 **11.5.1. Bleached Chemical Wood Pulp**

25 The primary discussion of potential dioxin releases from the bleached chemical wood  
26 pulp and paper industry is presented in Section 8.1. Many products made from bleached  
27 chemical wood pulp remain in use long after their production and, therefore, represent a potential  
28 reservoir. The limited data available on the dioxin concentrations in these products indicate

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1 decreasing levels over time, but the data are insufficient to make a reliable estimate of the  
2 cumulative amounts. As reported in Section 8.1, wood pulp is estimated to have contained  
3 500 g WHO<sub>98</sub> TEQ in 1987, 40 g WHO<sub>98</sub> TEQ in 1995, and 0.6 g WHO<sub>98</sub> TEQ in 2000. The  
4 total reservoir of CDD/CDFs in these products would be the cumulative amount of these  
5 products remaining in use minus any degradation or releases that have occurred. Insufficient  
6 information is available to estimate the size of the total reservoir or the possible releases.

### 8 **11.5.2. Chlorophenols**

9 The primary discussion of potential dioxin releases from chlorophenol production is  
10 presented in Section 8.4. The lower-chlorinated phenols have been used primarily as chemical  
11 intermediates in the manufacture of other pesticides. Pesticides are typically used the same year  
12 as they are produced and, therefore, are not a reservoir for future releases. The  
13 higher-chlorinated phenols (tetrachlorophenol and PCP) and their sodium salts have been used  
14 primarily for wood preservation. Wood products treated with these chemicals have long service  
15 lives and represent a potential reservoir. As discussed in Chapter 8, an estimate of average  
16 annual domestic PCP consumption during the period of 1970 to 1995 is about 400,000 MT. As  
17 reported in Section 8.4, PCP is estimated to have contained 20,000 g WHO<sub>98</sub> TEQ in 1987,  
18 4,800 g WHO TEQ in 1995, and 4,200 g WHO<sub>98</sub> TEQ in 2000. The limited data available on the  
19 dioxin concentrations in these products indicate decreasing levels over time, but the data are  
20 insufficient to make a reliable estimate of the cumulative amounts. It is unknown how much of  
21 the CDD/CDFs degrade in situ or escapes from the wood into the environment. Several recent  
22 field studies, as discussed in Chapter 8, demonstrate that CDD/CDFs do apparently leach into  
23 soil from PCP-treated wood, but the studies do not provide release-rate data. No studies were  
24 located that provide any measured CDD/CDF volatilization rates from PCP-treated wood.  
25 Although CDD/CDFs have very low vapor pressures, they are not bound to, nor do they react  
26 with, the wood in any way that would preclude volatilization. Several studies (see Chapter 8)  
27 have attempted to estimate potential CDD/CDF volatilization releases using conservative  
28 assumptions or modeling approaches, but these estimates span many orders of magnitude.  
29 Insufficient information is available to estimate the size of the total reservoir or the possible  
30 releases.

1 **11.5.3. Vinyl Chloride Products**

2 The primary discussion of potential dioxin releases from vinyl chloride production is  
3 presented in Section 8.3. Many vinyl chloride products remain in use long after their production  
4 and, therefore, represent a potential reservoir. Limited data are available on the dioxin  
5 concentrations in these products, but the data are insufficient to make a reliable estimate of the  
6 cumulative amounts. As discussed in Section 8.3, concentration and production data can be used  
7 to estimate that vinyl chloride contained 0.02 g I-TEQ in 1995 and 0.02 g I-TEQ in 2000. The  
8 total reservoir of CDD/CDFs in these products would be the cumulative amount of these  
9 products remaining in use minus any degradation or releases that have occurred. Insufficient  
10 information is available to estimate the size of the total reservoir or the possible releases.

11  
12 **11.5.4. Chloranil**

13 The primary discussion of potential dioxin releases from chloranil production is  
14 presented in Section 8.9. Chloranil is used to make dyes and pigments. These products may  
15 remain in use long after their production and, therefore, represent a potential reservoir. As  
16 discussed in Section 8.9, chloranil imports contained 64 g I-TEQ in 1987, 0.4 g I-TEQ in 1995,  
17 and 1.2 g I-TEQ in 2000. The total reservoir of CDD/CDFs in these products would be the  
18 cumulative amount of these products remaining in use minus any degradation or releases that  
19 have occurred. Insufficient information is available to estimate the size of the total reservoir or  
20 the possible releases.

21  
22 **11.5.5. Polychlorinated Biphenyls (PCBs)**

23 As discussed in Chapter 10 (the primary chapter on PCBs), production of PCBs ceased in  
24 the 1970s. However, they were used in a variety of products that can remain in use for long time  
25 periods, such as transformers and capacitors. The portion of these products that are still in use  
26 today represents potential reservoirs because releases can occur via leaks or during disposal  
27 operations. As discussed in the original report (see Section 10.6), approximately 568,000 MT of  
28 PCBs were used in the United States between 1930 and 1975. An estimated 50.3% were used in  
29 capacitors, and 26.8% were used in transformers. Assuming that these products contained an  
30 average of 8 mg WHO<sub>98</sub> TEQ<sub>p</sub>/kg (average concentration for Aroclor 1242, which accounted for  
31 over 50% of total sales—see Section 10.6 of original report), then a total of 3,500 kg of

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1 WHO<sub>98</sub> TEQ<sub>P</sub> were used in capacitors and transformers. It is unknown how much of this  
2 material is still in use or what amount of releases may be occurring.

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

6

<b>Product Reservoirs</b>
<b>Releases to Air</b>
Bleached Chemical Wood Pulp (Not quantifiable). Pentachlorophenol (Not quantifiable). Vinylchloride (Not quantifiable). Chloranil (Not quantifiable). PCBs (Not quantifiable).
<b>Releases to Soil</b>
Bleached Chemical Wood Pulp (Not quantifiable). Pentachlorophenol (Not quantifiable). Vinylchloride (Not quantifiable). Chloranil (Not quantifiable). PCBs (Not quantifiable).

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### 9 **11.6. SUMMARY AND CONCLUSIONS (ORIGINALLY SECTION 11.3)**

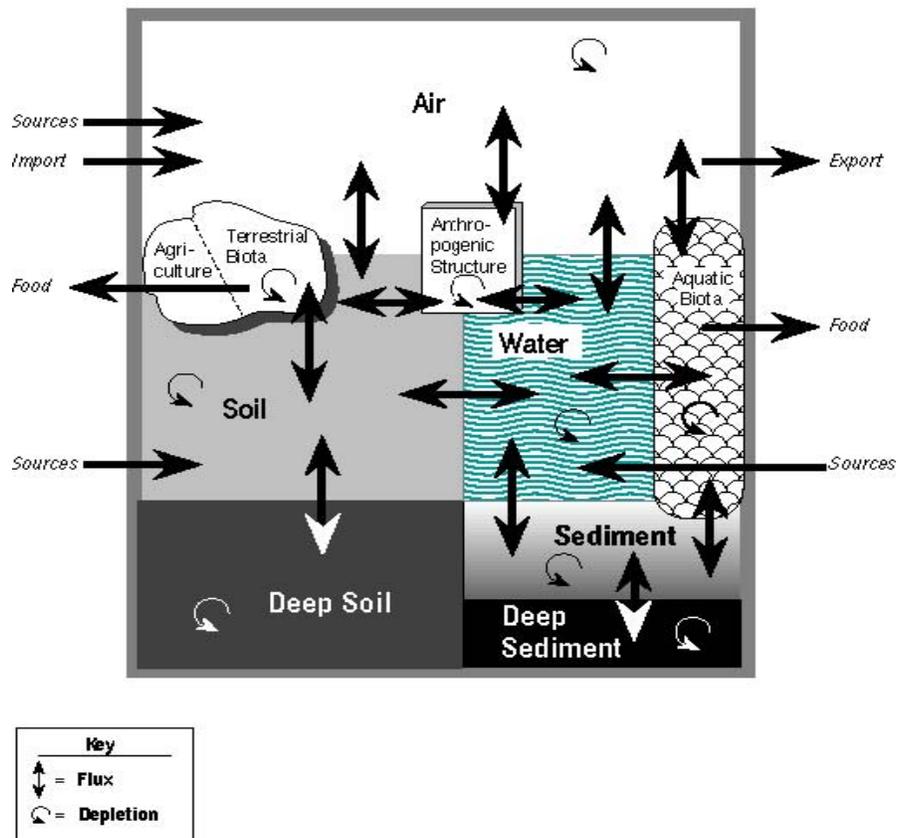
10 The original report presented a series of conclusions about the relative importance of  
11 reservoir sources and their implications to human exposure. Because this version of the  
12 document contains only slight revisions to reservoir source estimates, the same general  
13 observations made in the previous version still apply. In addition, reservoir sources are all still  
14 considered "preliminary", and thus not part of the quantitative inventory.

15

**Table 11-1. Amounts of CDD/CDFs Landfilled (g WHO<sub>98</sub> TEQ/year)**

<b>Source</b>	<b>1987</b>	<b>1995</b>	<b>2000</b>
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 <sup>a</sup>
Titanium smelting and refining			240 <sup>a</sup>
Chlor-alkali plants			3
Vinyl chloride plants			6
Complex organic chemical plants			118
Municipal wastewater treatment sludge	86	40	13
<b>Total</b>	<b>3,750</b>	<b>1,050</b>	<b>1,310</b>

<sup>a</sup>Based on TRI data (U.S. EPA, 2008).



**Fluxes Among Dioxin Reservoirs**

**Figure 11-1. Fluxes among environmental reservoirs.**

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