



# TOXICS RELEASE INVENTORY

## Guidance for Reporting Toxic Chemicals within the Dioxin and Dioxin-like Compounds Category

Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) requires certain facilities manufacturing, processing, or otherwise using listed toxic chemicals to report the annual quantity of such chemicals entering each environmental medium. Such facilities must also report pollution prevention and recycling data for such chemicals, pursuant to section 6607 of the Pollution Prevention Act, 42 U.S.C. 13106. EPCRA section 313 is also known as the Toxics Release Inventory (TRI).

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#### LIST OF ABBREVIATIONS AND ACRONYMS

BACT	Best Available Control Technology
BADT	Best Available Demonstrated Technology
CAAA	Clean Air Act Amendments
CAS	Chemical Abstract Service
CDDs	Chlorinated dibenzo-p-dioxins
CDFs	Chlorinated dibenzofurans
dscf	dry standard cubic foot
dscm	dry standard cubic meter
EPCRA	Emergency Planning and Community Right-to-Know Act of 1986
ESP	Electrostatic precipitator
g	gram
kg	kilogram
L	liter
lb	pounds
m <sup>3</sup>	cubic meter
MACT	Maximum Achievable Control Technology
NAICS	North American Industrial Classification System
ng	nanogram. 1 E-09 gram
°C	Temperature in Celsius
°F	Temperature in Fahrenheit
pg	picogram. 1 E-12 gram
s	seconds
SIC	Standard Industrial Classification Code
yr	year

## Section 1.0. INTRODUCTION

### Section 1.1. Background

On October 29, 1999, the Environmental Protection Agency (EPA) promulgated a final rule (64 FR 58666) adding a category of dioxin and dioxin-like compounds to the list of toxic chemicals subject to the reporting requirements under section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA). The reporting threshold for the category was also established as 0.1 grams manufactured, processed, or otherwise used. The category listing is:

Dioxin and dioxin-like compounds (Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical) (40 CFR 372.65(c))

The purpose of this document is to provide guidance on the reporting requirements of EPCRA section 313 for the dioxin and dioxin-like compounds category. EPCRA section 313 covered facilities that exceed the reporting threshold for the dioxin and dioxin-like compounds category are subject to the EPCRA section 313 annual reporting requirements beginning with reporting year 2000, with the first reports due by July 1, 2001.

This document explains the EPCRA section 313 reporting requirements, and provides guidance on how to estimate annual releases and other waste management quantities of dioxin and dioxin-like compounds to the environment from certain industries and industrial activities. Because each facility is unique, the recommendations presented may have to be adjusted to the specific nature of operations at your facility or industrial activity.

A primary goal of EPCRA is to increase the public's knowledge of, and access to, information on the presence and release and other waste management activities of EPCRA section 313 toxic chemicals in their communities. Under EPCRA section 313, certain facilities (see Section 1.2, below) exceeding certain thresholds (see Section 1.3) are required to submit reports (commonly referred to as Form R reports or Form A certification statements) annually. Reports must be submitted to EPA and State or Tribal governments, on or before July 1, for activities in the previous calendar year. The owner/operator of the facility on July 1 of the reporting deadline is primarily responsible for the report, even if the owner/operator did not own the facility during the reporting year. EPCRA also mandates that EPA establish and maintain a publicly available database consisting of the information reported under section 313. This database, known as the Toxics Release Inventory (TRI), can be accessed through several sources, including:

- EPA's Internet site, <https://www.epa.gov/toxics-release-inventory-tri-program>;
- Envirofacts Warehouse Internet site, <https://www3.epa.gov/enviro/>;
- TRI Explorer, [https://iaspub.epa.gov/triexplorer/tri\\_release.chemical](https://iaspub.epa.gov/triexplorer/tri_release.chemical);
- Microfiche in public libraries;
- EPA's annual National Analysis, <https://www.epa.gov/trinationalanalysis> and;

- Basic Data Files, <https://www.epa.gov/toxics-release-inventory-tri-program/tri-basic-data-files-calendar-years-1987-2016>.

The objectives of this guidance document are to:

- List EPCRA section 313 reporting requirements for the dioxin and dioxin-like compounds category;
- Promote consistency in the method of estimating annual releases and other waste management quantities of dioxin and dioxin-like compounds for particular industries and industrial classes;
- Reduce the level of effort expended by those facilities that prepare an EPCRA section 313 report for the dioxin and dioxin-like compounds category.

## **Section 1.2. Who Must Report?**

A plant, factory, or other facility is subject to the provisions of EPCRA section 313, if it meets all three of the following criteria:

- It is included in the following North American Industrial Classification System (NAICS) manufacturing codes (corresponding to Standard Industrial Classification (SIC) codes 20 through 39): 311\*, 312\*, 313\*, 314\*, 315\*, 316, 321, 322, 323\*, 324, 325\*, 326\*, 327, 331, 332, 333, 334\*, 335\*, 336, 337\*, 339\*, 111998\*, 113310, 211130\*, 212324\*, 212325\*, 212393\*, 212399\*, 488390\*, 511110, 511120, 511130, 511140\*, 511191, 511199, 512230\*, 512250\*, 519130\*, 541713\*, 541715\* or 811490\*. \*Exceptions and/or limitations exist for these NAICS codes.

Facilities included in the following NAICS codes (corresponding to SIC codes other than SIC codes 20 through 39): 212111, 212112, 212113 (corresponds to SIC code 12, Coal Mining (except 1241)); or 212221, 212222, 212230, 212299 (corresponds to SIC code 10, Metal Mining (except 1011, 1081, and 1094)); or 221111, 221112, 221113, 221118, 221121, 221122, 221330 (limited to facilities that combust coal and/or oil for the purpose of generating power for distribution in commerce) (corresponds to SIC codes 4911, 4931, and 4939, Electric Utilities); or 424690, 425110, 425120 (limited to facilities previously classified in SIC code 5169, Chemicals and Allied Products, Not Elsewhere Classified); or 424710 (corresponds to SIC code 5171, Petroleum Bulk Terminals and Plants); or 562112 (limited to facilities primarily engaged in solvent recovery services on a contract or fee basis (previously classified under SIC code 7389, Business Services, NEC)); or 562211, 562212, 562213, 562219, 562920 (limited to facilities regulated under the Resource Conservation and Recovery Act, subtitle C, 42 U.S.C. 6921 et seq.) (corresponds to SIC code 4953, Refuse Systems); and

- It has 10 or more full-time employees (or the equivalent of 20,000 hours per year); and

- It manufactures (includes imports), processes or otherwise uses any of the toxic chemicals listed on the EPCRA section 313 list in amounts greater than the established threshold quantities.

In addition, beginning with Executive Order 13148 signed in 1993, federal facilities are required to comply with the reporting requirements of EPCRA section 313 starting with calendar year 1994. This requirement is mandated regardless of the facility's NAICS or SIC code. The most recent Executive Order that continues this requirement is "Planning for Federal Sustainability in the Next Decade" (EO 13693, March 19, 2015).

### **Section 1.3. What are the Reporting Thresholds?**

Thresholds are specified amounts of toxic chemicals manufactured, processed, or otherwise used during the calendar year that trigger reporting requirements. The EPCRA section 313 dioxin and dioxin-like compounds category consists of seventeen specific compounds (see Section 1.5, Table 1-2) that are reported as a single chemical category. EPA regulations require threshold determinations for chemical categories to be based on the total mass of all the chemicals in that category (40 CFR 372.25(d)). Reporting is required for the dioxin and dioxin-like compounds category:

- If a facility *manufactures* 0.1 grams of dioxin and dioxin-like compounds over the calendar year.
- If a facility *processes* 0.1 grams of dioxin and dioxin-like compounds over the calendar year. (See the category qualifier in section 1.6)
- If a facility *otherwise uses* 0.1 grams of dioxin and dioxin-like compounds over the calendar year. (See the category qualifier in section 1.6)

The terms manufacture, process, and otherwise use are defined at 40 CFR §372.3 as:

*Manufacture* means to produce, prepare, import, or compound a toxic chemical. Manufacture also applies to a toxic chemical that is produced coincidentally during the manufacture, processing, use, or disposal of another chemical or mixture of chemicals, including a toxic chemical that is separated from that other chemical or mixture of chemicals as a byproduct, and a toxic chemical that remains in that other chemical or mixture of chemicals as an impurity.

*Otherwise use* means any use of a toxic chemical, including a toxic chemical contained in a mixture or other trade name product or waste, that is not covered by the terms "manufacture" or "process." Otherwise use of a toxic chemical does not include disposal, stabilization (without subsequent distribution in commerce), or treatment for destruction unless:

- (1) The toxic chemical that was disposed, stabilized, or treated for destruction was received from offsite for the purposes of further waste management; or

- (2) The toxic chemical that was disposed, stabilized, or treated for destruction was manufactured as a result of waste management activities on materials received from off-site for the purposes of further waste management activities. Relabeling or redistributing of the toxic chemical where no repackaging of the toxic chemical occurs does not constitute otherwise use or processing of the toxic chemical.

*Process* means the preparation of a toxic chemical, after its manufacture, for distribution in commerce:

- (1) In the same form or physical state as, or in a different form or physical state from, that in which it was received by the person so preparing such substance, or
- (2) As part of an article containing the toxic chemical. Process also applies to the processing of a toxic chemical contained in a mixture or trade name product.

The qualifier for the dioxin and dioxin-like compounds category places some limitations on what is covered by the category and thus certain processing or otherwise use activities that may involve dioxin and dioxin-like compounds are not reportable. See Section 1.6 for a detailed discussion of the qualifier and its impacts on reporting.

The quantities of dioxin and dioxin-like compounds included in threshold determinations are not limited to the amounts of these compounds released to the environment, they include all amounts of dioxin and dioxin-like compounds manufactured, processed, or otherwise at the facility. For example, some emission factors may include values for both before and after scrubbers, and while the after scrubber values would apply to release estimates, the before scrubber values would apply towards threshold calculations since this represents amounts that have been manufactured. Amounts estimated to be removed by scrubbers should also be reported according to how they are handled (e.g., released to land on-site, transferred off-site for disposal or destruction, etc.). If the only information that a facility has concerning the manufacturing, processing, or otherwise use of dioxin and dioxin-like compounds at the facility comes from emission factors, then those quantities can be used to determine threshold quantities.

EPA regulations require threshold determinations, and release and other waste management quantities for chemical categories to be based on the total mass of all the chemicals in the category (40 CFR 372.25(d)). Thus, in determining thresholds and release and other waste management quantities the amounts of all members of the category must be summed and included in the calculations. As with reporting for all EPCRA section 313 categories, one Form R is prepared for the dioxin and dioxin-like compounds category that contains the total amounts of all members of the category. All reporting for the dioxin and dioxin-like compounds category is to be in gram quantities (40 CFR 372.85), no reporting in grams of toxic equivalents (TEQs) is allowed. It is important to remember that EPCRA section 313 does not require any additional testing. As stated in EPCRA section 313(g)(2):

[i]n order to provide the information required under this section, the owner or operator of a facility may use readily available data (including monitoring data) collected pursuant to other provisions of law, or, where such data are not readily available, reasonable estimates of the amounts involved. Nothing in this section requires the monitoring or measurement of the quantities, concentration, or frequency of any toxic chemical released into the environment beyond that monitoring and measurement required under other provisions of law or regulation.

#### **Section 1.4. What is Form R Schedule 1?**

On May 10, 2007 (72 FR 26544), EPA published a final rule that expanded the reporting for the dioxin and dioxin-like compounds category to include member specific data for certain reporting elements. The member specific data is used by EPA to perform toxic equivalency (TEQ) computations which are made available to the public. The member specific data is captured on the Form R Schedule 1 which is an adjunct to the Form R that mirrors the data elements from Form R Part II Chemical-Specific Information sections 5, 6, and 8 (current year only). Form R Schedule 1 requires the reporting of the individual grams data for each member of the dioxin and dioxin-like compounds category present. Facilities that file Form R reports for the dioxin and dioxin-like compounds category are required to determine if they have any of the information required by the Form R Schedule 1. Facilities that have any of the information required by Form R Schedule 1 must submit individual member data via the Form R Schedule 1 in addition to the Form R.

The only data reported on the Form R Schedule 1 is the mass quantity information required in sections 5, 6, and 8 (current year only) of the Form R. All of the other information required in sections 5, 6, and 8 of the Form R (off-site location names, stream or water body names, etc.) would be the same so this information is not duplicated on Form R Schedule 1. For example, if a facility reported 5.3306 grams on Form R Section 5.1 for fugitive or non-point air emissions for the dioxin and dioxin-like compounds category then the facility would report on the Form R Schedule 1 the grams data for each individual member of the category that contributed to the 5.3306 gram total. The sum of the gram quantities reported for each individual member of the category should equal the total gram quantity reported for the category on Form R for each data element (see examples in Figure 1). The Form R Schedule 1 provides boxes for recording the gram quantities for all 17 individual members of the dioxin and dioxin-like compounds category. The boxes on the Form R Schedule 1 for each release type are divided into 17 boxes. Each of the boxes (1-17) corresponds to the individual members of the dioxin category as presented in **Table 1-2**. The NA box has the same meaning on Form R Schedule 1 as it does on the Form R and should only be marked if it is marked on the Form R. It is extremely important that facilities enter their grams data for the individual members of the category based on the order shown in **Table 1-2 Members of the EPCRA Section 313 Dioxin and Dioxin-like Compounds Category**. This information will be used to calculate toxic equivalency values using toxic equivalency factors that are specific to each member of the category.

More details on how to report using Form R Schedule 1 can be found in section E of the annual “Toxic Chemical Release Inventory Reporting Forms and Instructions” available at: [https://ofmpub.epa.gov/apex/guideme\\_ext/f?p=guideme\\_ext:41](https://ofmpub.epa.gov/apex/guideme_ext/f?p=guideme_ext:41)

**Figure 1. Hypothetical Form R, Section 5.1 and Form R Schedule 1, Section 5.1**

**Form R Section 5 Example**

SECTION 5. QUANTITY OF THE TOXIC CHEMICAL ENTERING EACH ENVIRONMENTAL MEDIUM ON-SITE					
			A. Total Release (pounds/year*) (Enter a range code** or estimate)	B. Basis of Estimate (Enter code)	C. Percent from Stormwater
5.1	Fugitive or non-point air emissions	NA <input type="checkbox"/>	5.3306	M2	

**Form R Schedule 1 Section 5 Example**

SECTION 5. QUANTITY OF DIOXIN AND DIOXIN-LIKE COMPOUNDS ENTERING EACH ENVIRONMENTAL MEDIUM ON-SITE										
		5.1	NA	5.2		NA	5.3 Discharges to receiving streams or water bodies (Enter data for one stream or water body per box) NA <input type="checkbox"/>			
		Fugitive or non-point air emissions		Stack or point air emissions		5.3.1			5.3.2	5.3.3
D. Mass (grams) of each compound in the category (1-17)	1	0.0035								
	2	0.0059								
	3	0.0071								
	4	0.0008								
	5	0.0065								
	6	0.0923								
	7	0.5720								
	8	0.0723								
	9	0.0695								
	10	0.0399								
	11	0.3562								
	12	0.1309								
	13	0.0132								
	14	0.0815								
	15	1.4625								
	16	0.3126								
	17	2.1039								

If additional pages of Section 5.3 are attached, indicate the total number of pages in this box

and indicate the Section 5.3 page number in this box  (Example: 1, 2, 3, etc.)

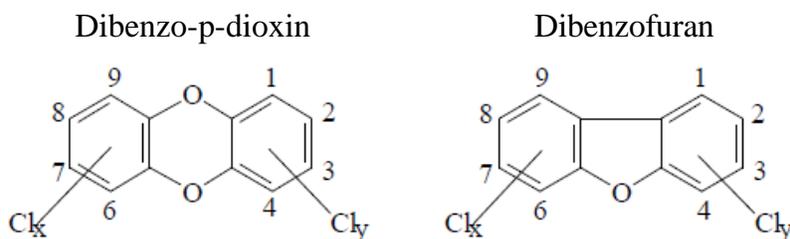
**Section 1.5. What are Dioxin and Dioxin-like Compounds and Which Chemicals are Included in the EPCRA Section 313 Dioxin and Dioxin-like Compounds Category?**

Polychlorinated dibenzo-para(p)-dioxins (CDDs) and polychlorinated dibenzofurans (CDFs) constitute a group of persistent, bioaccumulative, toxic (PBT) chemicals that are termed ‘dioxin-like.’ The term, ‘dioxin-like’ refers to the fact that these compounds have similar chemical structure, similar physical-chemical properties, and invoke a common battery of toxic responses. An important aspect to this definition is that the CDDs and CDFs must have chlorine substitution of hydrogen atoms at the 2, 3, 7, and 8 positions on the benzene rings.

A molecule of dibenzo-p-dioxin (DD) and dibenzofuran (DF) is a triple-ring structure consisting of two benzene rings interconnected by a third oxygenated ring (i.e., a ring containing an oxygen atom). In DD, the middle oxygenated ring contains two oxygen atoms that connect the

benzene rings while in DF, the oxygenated ring contains one oxygen atom that joins the benzene rings. The molecular structure of DD and DF is depicted in Figure 2. As can be discerned in Figure 2, there is the possibility of substituting hydrogen atoms with chlorine atoms (or other halogens) at eight substituent positions along the DD and DF molecules (i.e., positions 1, 2, 3, 4, 6, 7, 8, or 9). This pattern of substitution creates the possibility of 75 chlorodibenzo-p-dioxin and 135 chlorodibenzofuran compounds. These individual compounds are technically referred to as congeners. Homologue groups are groups of congeners that have the same number of chlorine atoms attached to the molecule, but substituted in different positions as indicated by  $Cl_x$  and  $Cl_y$  in Figure 2. The prefix mono, di, tri, tetra, penta, hexa, hepta, and octa designates the total number of chlorines in the nomenclature of homologue groupings (i.e., molecules with either 1, 2, 3, 4, 5, 6, 7, or 8 chlorine atoms attached to the carbons). Isomerism is another important chemical descriptor, and refers to compounds with the same molecular formula (e.g., the same number of carbon, hydrogen, and chlorine atoms) but that differ by the location of the chlorine atoms on the benzene rings. Table 1-1 displays the total number of positional CDD and CDF isomers that are possible within each homologue group. The compounds with chlorine substitution in the 2, 3, 7, 8-positions on the molecule are the most toxic and bioaccumulate in mammalian systems, including humans.

**Figure 2. Chemical Structure of Dioxin-Like Compounds**



**Table 1-1. Homologues and Positional Isomers of CDDs, CDFs**

<i>Homologue (prefix)</i>	<i>Chlorine Atoms</i>	<i>Isomers of CDDs</i>	<i>Isomers of CDFs</i>
Mono	1	2	4
Di	2	10	16
Tri	3	14	28
Tetra (T)	4	22	38
Penta (Pe)	5	14	28
Hexa (Hx)	6	10	16
Hepta (Hp)	7	2	4
Octa (O)	8	1	1
Total possible congeners		75	135

The EPCRA section 313 dioxin and dioxin-like compounds category consists of seventeen specific CDD and CDF compounds. Only those CDD and CDF compounds with chlorine substitution in the 2, 3, 7, 8-positions on the molecule are reportable under the EPCRA section 313 dioxin and dioxin-like compounds category. Table 1-2 lists all of the members of the EPCRA section 313 dioxin and dioxin-like compounds category by CAS number, name and abbreviated name. These are the only CDD and CDF compounds that are reportable under the EPCRA section 313 dioxin and dioxin-like compounds category. The term “dioxin,” as in “dioxin and dioxin-like compounds” refers to the most widely studied of these compounds, 2,3,7,8-tetrachlorodibenzo-p-dioxin (CAS No. 1746-01-6). Throughout this document the phrase “dioxin and dioxin-like compounds” refers to the seventeen chemicals listed in Table 1-2.

**Table 1-2. Members of the EPCRA Section 313 Dioxin and Dioxin-like Compounds Category**

CAS No.	Chemical Name	Abbreviated Name	#Label*
CDDs			
1746-01-6	2,3,7,8-tetrachlorodibenzo-p-dioxin	2,3,7,8-TCDD	1
40321-76-4	1,2,3,7,8-pentachlorodibenzo-p-dioxin	1,2,3,7,8-PeCDD	2
39227-28-6	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	1,2,3,4,7,8-HxCDD	3
57653-85-7	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	1,2,3,6,7,8-HxCDD	4
19408-74-3	1,2,3,7,8,9-hexachlorodibenzo-p-dioxin	1,2,3,7,8,9-HxCDD	5
35822-46-9	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	1,2,3,4,6,7,8-HpCDD	6
3268-87-9	1,2,3,4,6,7,8,9-octachlorodibenzo-p-dioxin	1,2,3,4,6,7,8,9-OCDD	7
CDFs			
51207-31-9	2,3,7,8-tetrachlorodibenzofuran	2,3,7,8-TCDF	8
57117-41-6	1,2,3,7,8-pentachlorodibenzofuran	1,2,3,7,8-PeCDF	9
57117-31-4	2,3,4,7,8-pentachlorodibenzofuran	2,3,4,7,8-PeCDF	10
70648-26-9	1,2,3,4,7,8-hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF	11
57117-44-9	1,2,3,6,7,8-hexachlorodibenzofuran	1,2,3,6,7,8-HxCDF	12
72918-21-9	1,2,3,7,8,9-hexachlorodibenzofuran	1,2,3,7,8,9-HxCDF	13
60851-34-5	2,3,4,6,7,8-hexachlorodibenzofuran	2,3,4,6,7,8-HxCDF	14
67562-39-4	1,2,3,4,6,7,8-heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF	15
55673-89-7	1,2,3,4,7,8,9-heptachlorodibenzofuran	1,2,3,4,7,8,9-HpCDF	16
39001-02-0	1,2,3,4,6,7,8,9-octachlorodibenzofuran	1,2,3,4,6,7,8,9-OCDF	17

\*For filling out the distribution of each member of the category on Form R Schedule 1.

### Section 1.5.1. Formation of Dioxin and Dioxin-like Compounds During Combustion

More than a decade of combustion research has contributed to a general understanding of the central molecular mechanisms that form CDDs and CDFs emitted from combustion sources. Current understanding of the conditions necessary to form CDDs and CDFs were primarily derived from studying full-scale municipal solid waste incinerators (MSWIs), augmented with observations involving the experimental combustion of synthetic fuels and feeds within the laboratory. However, the formation mechanisms elucidated from these studies are generally relevant to most combustion systems in which organic material is burned with chlorine. Intensive studies have examined MSWIs from the perspective of identifying the specific formation mechanism(s) that occur within the system. This knowledge may lead to methods that prevent the formation of CDDs and CDFs and their release into the environment. Although much has been learned from such studies, how to completely prevent CDDs/CDFs from forming during the combustion of certain organic materials in the presence of a source of chlorine and oxygen is still unknown. The wide variability of organic materials incinerated and thermally processed by a wide range of combustion technologies that have variable temperatures, residence times, and oxygen requirements adds to this complex problem. However, central chemical events that participate in forming CDDs and CDFs can be identified by evaluating emission test results from MSWIs in combination with laboratory experiments.

CDD/CDF emissions from combustion sources can potentially be explained by three principal mechanisms, which should not be regarded as being mutually exclusive. The first is that CDDs and CDFs are present as contaminants in the combusted organic material, and pass through the furnace and are emitted unaltered. The second is that CDD/CDFs ultimately form from the thermal breakdown and molecular rearrangement of precursor ring compounds, which are defined as chlorinated aromatic hydrocarbons with a structural resemblance to the CDD and CDF molecules. Ringed precursors emanated from the combustion zone are a result of the incomplete oxidation of the constituents of the feed (i.e., products of incomplete combustion). The third mechanism, similar to the second, is that CDD/CDFs are synthesized *de novo*. *De novo* synthesis describes a pathway of forming CDD/CDFs from heterogeneous reactions on fly ash involving carbon, oxygen, hydrogen, chlorine, and a transition metal catalyst. With these reactions, intermediate compounds having an aromatic ring structure are formed. Studies in this area suggest that aliphatic compounds, which arise as products of incomplete combustion, may play a critical role in initially forming simple ring molecules, which later evolve into complex aromatic precursors. CDD/CDFs are then formed from the intermediate compounds. In both mechanisms (2) and (3), formation occurs outside the furnace, in the so-called post-combustion zone. Particulate bound carbon is suggested as the primary reagent in the *de novo* syntheses pathway.

Although chlorine is an essential component for the formation of CDD/CDFs in combustion systems, the empirical evidence indicates that, for commercial scale incinerators, chlorine levels in feed are not the dominant controlling factor for rates of CDD/CDF stack emissions. Important factors which can affect the rate of CDD/CDF formation include the overall combustion efficiency, post-combustion flue gas temperatures and residence times, and the availability of surface catalytic sites to

support CDD/CDF synthesis. Data from bench, pilot and commercial scale combustors indicate that CDD/CDF formation can occur by a number of mechanisms. Some of these data, primarily from laboratory and pilot scale combustors, have shown direct correlation between chlorine content in fuels and rates of CDD/CDF formation. Other data, primarily from commercial scale combustors, show little relation with availability of chlorine and rates of CDD/CDF formation. The conclusion that chlorine in feed is not a strong determinant of CDD/CDF emissions applies to the overall population of commercial scale combustors. For any individual commercial scale combustor, circumstances may exist in which changes in chlorine content of feed could affect CDD/CDF emissions. For uncontrolled combustion, such as open burning of household waste, chlorine content of wastes may play a more significant role in affecting levels of CDD/CDF emissions than observed in commercial scale combustors. For a more detailed discussion of the mechanisms of formation and the role of chlorine in the formation kinetics, the reader may refer to: Part 1: Estimating Exposure to Dioxin-Like Compounds; Volume 1: *Sources of Dioxin-Like Compounds in the United States*; Chapter 2: *Mechanisms of formation of dioxin-like compounds during combustion of organic materials*; In: Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-dioxin. EPA/600/P-00/001Cb, December 2003. NAS Review Draft. Available at: [https://cfpub.epa.gov/ncea/iris\\_drafts/dioxin/nas-review/pdfs/part1\\_vol1/dioxin\\_pt1\\_vol1\\_ch02\\_dec2003.pdf](https://cfpub.epa.gov/ncea/iris_drafts/dioxin/nas-review/pdfs/part1_vol1/dioxin_pt1_vol1_ch02_dec2003.pdf)

### **Section 1.6. What Activities are Covered by the Qualifier for the Dioxin and Dioxin-like Compounds Category?**

The dioxin and dioxin-like compounds category has the following activity qualifier that describes what must be reported under the category:

“Manufacturing; and the processing or otherwise use of dioxin and dioxin-like compounds if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical.”

This qualifier states that if a facility manufactures dioxin and dioxin-like compounds then those quantities must be applied towards the 0.1 gram manufacturing threshold and included in release and other waste management calculations. Manufacture includes the coincidental production of dioxin and dioxin-like compounds during any process (e.g., a combustion process, a chemical manufacture process). Note that, as discussed in Section 1.3, the EPCRA section 313 definition of manufacture includes importing. The qualifier also covers the processing or otherwise use of dioxin and dioxin-like compounds, but only if the dioxin and dioxin-like compounds are present as contaminants in a chemical and if they were created during the manufacturing of that chemical. This means that if a facility processes or otherwise uses a chemical or mixture that contains dioxin and dioxin-like compounds that were created during the manufacturing of that chemical or mixture, then the dioxin and dioxin-like compounds must be included in threshold determinations and release and other waste management calculations. However, if the dioxin and dioxin-like compounds were already present in a product being processed or otherwise used and were not created during the manufacture of that

product (such as at food processing plants where dioxin and dioxin-like compounds may be present in the incoming raw materials) the dioxin and dioxin-like compounds are not reportable and do not need to be included in threshold determinations or release and other waste management calculations.

Examples of the impacts of the dioxin and dioxin-like compounds category qualifier on what is reportable:

**Example 1:** A facility manufactures chemical A and in doing so, the facility also manufactures dioxin or dioxin-like compounds. Because EPCRA section 313 defines “manufacturing” to include production, the facility would have to include the dioxin or dioxin-like compounds it produced in its threshold determinations and release and other waste management calculations. This is true regardless of whether the compounds are present as contaminants in chemical A since the chemical listing for dioxin or dioxin-like compounds contains no modifications to the term manufacture as defined under EPCRA section 313.

**Example 2:** A facility processes or otherwise uses chemical A. Dioxin or dioxin-like compounds are present in chemical A as contaminants. The dioxin or dioxin-like compounds present in chemical A were created during the manufacturing of chemical A. In this case, the facility would have to include the dioxin or dioxin-like compounds present in chemical A in its threshold determinations and release and other waste management calculations.

Note that if chemical A is processed into a different product but chemical A still exists in that product (i.e., it has not been converted into a different chemical) then the dioxin and dioxin-like compounds must be included in threshold determinations and release and other waste management calculations.

**Example 3:** A facility processes or otherwise uses chemical B. Dioxin or dioxin-like compounds are present in chemical B as contaminants. However, the dioxin or dioxin-like compounds in chemical B *were not* created during the manufacturing of chemical B (they were introduced from an environmental source or created during the manufacture of a precursor to chemical B). In this case, because one of the two limitations in the category qualifier was not satisfied, the facility *would not* have to include the dioxin or dioxin-like compounds present in chemical B in its threshold determinations and release and other waste management calculations.

**Example 4:** Dioxin or dioxin-like compounds are present in chemical A as contaminants. The dioxin or dioxin-like compounds present in chemical A were created during the manufacturing of chemical A. Facility X uses or processes chemical A to manufacture chemical C. No new dioxin or dioxin-like compounds were created in the manufacture of chemical C, but chemical C does contain the dioxin or dioxin-like

chemicals that were present in chemical A. Because facility X is using or processing chemical A, which contains dioxin or dioxin-like compounds as contaminants that were created during the manufacturing of chemical A, facility X would have to include the dioxin or dioxin-like compounds present in chemical A in its threshold determinations and release and other waste management calculations. This is true regardless of what facility X does with chemical C (uses it on site, sells it, etc.).

Facility X then sells chemical C to facility Y. Although chemical C contains dioxin or dioxin like compounds as contaminants, those compounds *were not* created during the manufacture of chemical C (they were created during the manufacture of chemical A). Because one of the two limitations in the category qualifier was not satisfied, facility Y *would not* have to include the dioxin or dioxin-like compounds present in chemical C in its threshold determinations and release and other waste management calculations.

**Example 5:** Facility X imports chemical D into the country. Chemical D contains dioxin or dioxin-like compounds. Because EPCRA section 313 defines “manufacturing” to include importing, facility X would have to include the dioxin or dioxin-like compounds present in chemical D in its threshold determinations and release and other waste management calculations. This is true regardless of whether the compounds are present as contaminants or when they were created since the chemical listing for dioxin or dioxin- like compounds contains no modifications to the term manufacture as defined under EPCRA section 313.

Facility X then sells chemical D to facility Y. Facility Y processes or uses chemical D on site. Facility Y must determine if the dioxin or dioxin-like compounds present in chemical D: 1) are present as contaminants, and 2) were created during the manufacture of chemical D. If the answers to *both* questions are “Yes,” then facility Y would have to include the dioxin or dioxin-like compounds present in chemical D in its threshold determinations and release and other waste management calculations. In answering those questions, facility Y should use the best available information.

**Example 6:** A waste management facility accepts wastes that contain dioxin or dioxin-like compounds for the purposes of on-site waste management. By accepting waste for on- site waste management, the facility is otherwise using the dioxin or dioxin-like compounds in that waste. The facility must determine if the dioxin or dioxin-like compounds in the waste: 1) are present as contaminants, and 2) were created during the manufacture of the waste or any chemicals in the waste. If the answers to *both* questions are “Yes,” then the facility would have to include the dioxin or dioxin-like compounds present in the waste in its threshold determinations and release and other waste management calculations. In answering those questions, the facility should use the best available information.

There are several chemicals and/or products that EPA has identified as having the potential to contain dioxin and dioxin-like compounds manufactured as by-products during the manufacturing process for those chemicals. These chemicals include, but are not limited to:

<u>CAS No.</u>	<u>Chemical/Product Name</u>	<u>Typical Uses</u>
118-75-2	Chloranil	dyes, pigments, pesticides
87-86-5	Pentachlorophenol (PCP)	wood preserving, pesticides
107-06-2	Ethylene dichloride (EDC) (manufactured by oxychlorination)	vinyl chloride production, gasoline, paints and varnishes, metal degreasing, scouring compounds, organic synthesis, solvent, fumigant
94-75-7	2,4-D	pesticides
1928-43-4	2,4-D Ester Herbicides	pesticides
	Bleached chemical wood pulp	white paper products

### **Section 1.7. What Other Changes to the EPCRA Section 313 Reporting Requirements Apply to the Dioxin and Dioxin-like Compounds Category?**

EPA has also made modifications and/or clarifications to certain reporting exemptions and requirements for the PBT chemicals that are subject to the lower reporting thresholds; this includes the dioxin and dioxin-like compounds category. Each of the changes as they apply to dioxin and dioxin-like compounds category is discussed in the following subsections.

#### **Section 1.7.1. *De Minimis* Exemption**

The *de minimis* exemption allows facilities to disregard certain minimal concentrations of non-PBT chemicals in mixtures or other trade name products they process or otherwise use when making threshold determinations and release and other waste management calculations.

EPA eliminated the *de minimis* exemption for the dioxin and dioxin-like compounds category (40 CFR 372.38(a)). This means that facilities are required to include all amounts of dioxin and dioxin-like compounds in threshold determinations and release and other waste management calculations regardless of the concentration of the dioxin and dioxin-like compounds in mixtures or trade name products.

#### **Section 1.7.2. Form A Exclusion**

The “TRI Alternate Threshold for Facilities with Low Annual Reportable Amounts,” provides facilities otherwise meeting EPCRA section 313 reporting thresholds the option of certifying on Form A provided that they do not exceed 500 pounds for the total annual reportable amount for that chemical, and that their amounts manufactured or processed or otherwise used do not exceed one million pounds.

EPA has excluded the dioxin and dioxin-like compounds category from the “TRI Alternate Threshold for Facilities with Low Annual Reportable Amounts” (40 CFR 372.27(e)). Therefore, submitting a Form A rather than a Form R is not an option for the dioxin and dioxin-like compounds category.

### **Section 1.7.3. Range Reporting**

For facilities with total annual releases or off-site transfers of an EPCRA section 313 chemical of less than 1,000 pounds, EPA allows the amounts to be reported on the Form R either as an estimate or by using ranges.

EPA has eliminated range reporting for the dioxin and dioxin-like compounds category (40 CFR 372.85(b)). This means that for those sections of the Form R for which range reporting is an option, the option cannot be used when reporting on the dioxin and dioxin-like compounds category. Thus facilities must report an actual number rather than a selected range.

### **Section 1.7.4. Data Precision**

Facilities should report for the dioxin and dioxin-like compounds category at a level of precision supported by the accuracy of the underlying data and the estimation techniques on which the estimate is based. However, the smallest quantity that needs to be reported on the Form R for the dioxin and dioxin-like compounds category is 0.0001 grams (i.e., 100 micrograms).

Example: If the total quantity for Section 5.2 of the Form R (i.e., stack or point air emissions) is 0.00005 grams or less, then zero can be entered. If the total quantity is between 0.00005 and 0.0001 grams then 0.0001 grams can be entered or the actual number can be entered (e.g., 0.000075).

## **Section 2.0. GUIDANCE ON ESTIMATING ENVIRONMENTAL RELEASES OF DIOXIN AND DIOXIN-LIKE COMPOUNDS**

### **Section 2.1. General Guidance**

EPA is providing the following guidance which may be used by facilities in estimating and reporting annual releases and other waste management quantities for the dioxin and dioxin-like compounds category. EPA supports the use of three different approaches for estimating annual releases of dioxin and dioxin-like compounds from facilities subject to reporting:

1. Use of actual facility-specific monitoring data
2. Use of facility-specific emission factors
3. Use of facility-specific EPA default emission factors

In general EPA considers these three approaches to be hierarchical. In most situations, monitoring or directly measured data obtained at your facility provides the best and most accurate estimate of annual releases of dioxin and dioxin-like compounds. Note that, as discussed under Section 1.3, EPCRA section 313 does not require any additional monitoring or measurements beyond that monitoring and measurement required under other provisions of law or regulation. Depending on the adequacy and quality of the data in terms of sampling and laboratory methods used to ascertain the data, monitoring data may or may not be a facility's best available data. To be representative of annual releases of dioxin and dioxin-like compounds, the monitoring and sampling should have been taken under conditions representative of the facility's general operating and/or production conditions. In the absence of such monitoring data two additional approaches are recommended, which, to the extent possible, should also be based on conditions representative of the facility's general operating and/or production conditions.

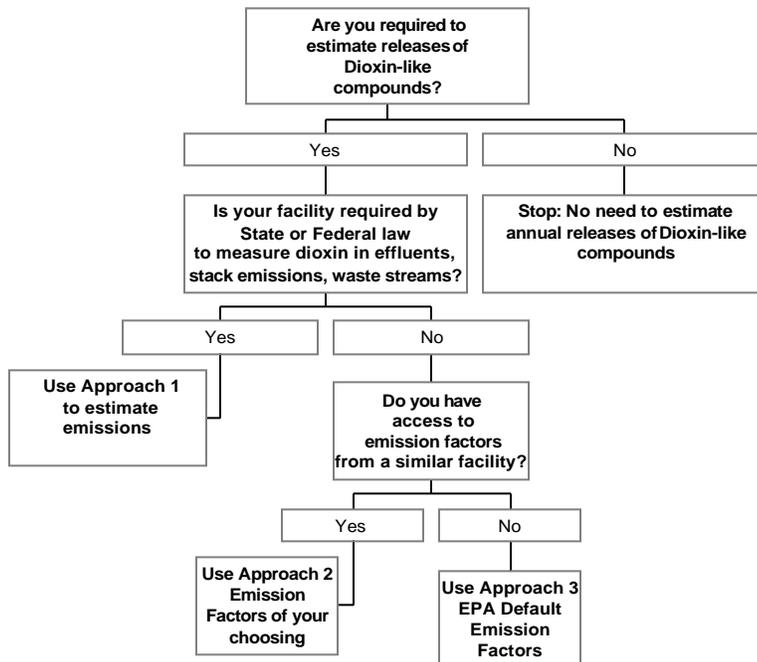
- First, facilities may use facility-specific emission factors that they believe are the best 'fit' to their facility. This means that the facility may use emission factors developed from the sampling and monitoring of dioxin and dioxin-like compounds at a similar facility. Reports of sampling emission and effluent streams should be collected and reviewed from facilities that are most similar in technology, design, operation, capacity, auxiliary fuels used, products produced, the manufacturing process, waste products generated, Industrial Classification Code, feedstocks used, air/water pollution control systems, etc. An important aspect in selecting an emission factor for a combustion process is temperature. A temperature inlet to the air pollution control device that is below 200° Celsius or above 450° Celsius will result in minimal stack release of dioxin and dioxin-like compounds. Therefore, in defining similarity of process, the facility operator is encouraged to examine, and then match, the temperature reported at the facility that you selected to be representative of potential emissions from your facility. Data from similar facilities within the same industry sector compiled by industry technical organizations may be a good source of facility-specific emission factors.
- Second, facilities that cannot use either of these approaches may estimate their annual releases through the use of default emission factors provided by EPA in Section 4 of this

guidance. Selection of more site-specific emission factors are preferred.

The owner/operator of the facility should determine whether one of these three approaches would provide an accurate reflection of the potential for releases of dioxin and dioxin-like compounds from the facility or whether some other method would be more appropriate. Figure 3 is a 'decision tree' highlighting the basic questions one should ask when selecting the appropriate emission factor approach. The first step in the 'decision tree' is to determine whether your facility meets the reporting requirements of EPCRA section 313, however, it is possible that before you can make a final determination on whether your facility meets the EPCRA section 313 reporting requirements you may have to go ahead and use one of the estimation methods to help determine if your facility will exceed reporting thresholds.

When selecting the estimation method to be used, EPA recommends that the facility be able to document the rationale employed in making the selection. When documenting the annual releases and other waste management quantities of dioxin and dioxin-like compounds, EPA recommends that the facility indicate which of these three approaches was used in deriving the estimate. The owner/operator is encouraged to exercise 'best engineering judgement' when arriving at the decision on the most appropriate approach to use. A more detailed explanation of each of these approaches follows.

**Figure 3. Decision Tree For Selecting Emission Estimation Technique**



In the context of this guidance, the term “best engineering judgment” engenders one or more of the following:

- Knowledge of the manufacturing/industrial process and process flow;
- Knowledge of the chemical feed stocks used in the manufacturing/industrial process
- Knowledge of the feedstocks/fuels used in providing a source of energy for the process;
- Knowledge of the water pollution control system/technology and contaminant removal efficiencies used to treat industrial wastewater;
- Knowledge of the waste products derived from operations and manufacturing;
- Knowledge of the air pollution control equipment and contaminant removal efficiencies used to control toxic air pollutants.

When applying ‘best engineering judgement’ to a determination of the appropriate emission factor approach to use to calculate emissions and releases of dioxin-like compounds for your facility, it is important to:

- Obtain engineering test reports and/or literature references of dioxin emissions/releases from facilities that are within your industry code (NAICS or SIC).

- Compare your facility design, function and operations with other facilities that have been tested or sampled for emissions of dioxin-like compounds. This will allow you to match the two processes and make the determination as to how representative these emission factors are to your facility;

- If you are unable to locate representative emission factors for your facility, then you may elect to use EPA’s default emission factors appropriate for your facility.

### **Section 2.1.1. Approach 1 - Use Actual Facility-Specific Monitoring Data**

This approach allows the facility to estimate annual releases of dioxin and dioxin-like compounds to the air, water and land, as well as other waste management quantities, based on measured data derived at the facility. A facility may be required to perform monitoring under provisions of the Clean Air Act (CAA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), or other regulations. If this is the case, then these data should be available for developing release estimates. Data may have also been collected for your facility for compliance monitoring purposes associated with a state or federal permit. If only a small amount of direct measurement data are available or if you believe the monitoring data are not representative, you should determine if an alternative estimation method would give a more accurate result. With regard to the manner in which non-detects (ND) are reported, refer to Section 2.2.

### **Section 2.1.2. Approach 2 - Use Facility-Specific Emission Factors**

Emission factors are the fundamental tools in this guidance for estimating releases of dioxin and dioxin-like compounds. An emission factor is a representative value that is intended to relate the quantity

of dioxin and dioxin-like compounds released to the open environment with a measure of industrial activity associated with the release. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, or duration of the activity emitting the contaminant. Examples of emission factors include: nanograms (ng) of dioxin and dioxin-like compounds emitted into air per kilogram (kg) of coal burned; picogram (pg) of dioxin and dioxin-like compounds discharged into surface water per liter (L) of wastewater; ng dioxin and dioxin-like compounds transferred to land disposal per kg of sludge produced at your facility. Emission factors facilitate estimation of environmental releases from various sources of releases of dioxin and dioxin-like compounds when the annual activity level of the facility is known. Your emission factor should be assumed to be representative of long-term averages for your facility. The general equation for emission estimation is:

$$\text{Annual Release} = \text{Emission Factor} \times \text{Annual Activity Level}$$

$$R = EF \times A$$

where:

$R$  = annual release of dioxin and dioxin-like compounds, (i.e., g/yr)

$A$  = activity level or production rate, (e.g., kg of material processed per year)

$EF$  = dioxin emission factor, (e.g., g dioxin released/kg material processed/time)

EF is to represent the emission of dioxin and dioxin-like compounds into the open environment at the 'end-of-the-pipe'. The extent of completeness and detail of the emissions is determined by the information available from published references. Emissions from some processes are better documented than others. When electing to use this approach, EPA recommends that the facility maintain documentation on the other facility(ies) engineering test reports or the source of the industry- specific data compiled by technical organizations that were evaluated and used in deriving your emission factors. The documentation should clarify why the other facility is a close analogy to your facility based on similarity of design, operations, feed stocks, end products, industry code, manufacturing process, combustion process, and pollution control systems. Sources of information that may be helpful in Approach 2 include:

- State Regulatory Agencies. In the development of regulatory requirements for specificities, it is often the case that State environmental agencies have issued permits for the allowable discharge of dioxin-like compounds to the environment from facilities similar to your own. The State Agency may have reliable test reports information attendant to permitting such facilities. These test reports are usually kept in the public record.
- Trade Associations. Several industries are represented by Trade Associations that function to foster the interests of a particular industrial sector. Such trade associations are comprised of member companies. Often member companies make engineering test reports available to the Trade Association members.
- EPA Regulatory Dockets. EPA regulatory dockets are maintained as a central repository of information EPA used in a rule making process. Such dockets and their contents are open to

the public for inspection and photo copying. The Federal Register preamble announcing proposed or final rule under one of the statutory authorities of EPA will identify the location of the regulatory docket and provide information as to how one may access information in the docket. The docket does contain technical information, including test reports data, that was used in the development of the regulatory requirements.

- EPA Internet Sites. The EPA maintains a central site on the Internet, i.e., <https://www.epa.gov>. This home page provides a useful base from which to access EPA databases, reports and studies, and to conduct searches by topic. Complete documents can be electronically accessed from this site. An example of an EPA site having abundant information on air emission factors is the Technical Air Pollution Resources maintained by EPA's Office of Air Quality Planning and Standards. This site has an URL: <https://www.epa.gov/technical-air-pollution-resources>.
- Engineering and Science Libraries. Public and private universities often times allow public access to technical literature housed within university libraries. This is particularly true of universities having schools of engineering and science.

### **Section 2.1.3. Approach 3 - Use Facility-Specific EPA Default Emission Factors**

With this approach, EPA is providing tables of emission factors for specific sources, that, when multiplied by an appropriate measure of annual activity level at your facility, will result in an estimate of annual releases of the sum of dioxin and dioxin-like compounds (i.e., the 17 compounds of CDDs and CDFs) from your facility. Emission factors are used to calculate annual releases in situations in which the facility has not measured CDDs and CDFs in its effluents or emission streams. The EPA default emission factors were derived from the available monitoring data deemed to be representative of the source category (or segments of the source category that differ in configuration, fuel type, manufacturing process, feedstocks, pollution control systems, etc.). Implicit in the use of the default emission factors is the assumption that facilities with similar design and operating characteristics should have a similar potential for release of dioxin and dioxin-like compounds. The default emission factors are more accurately applied to an entire source category, because it is representative of the average emissions of all tested facilities in the category. This introduces a significant degree of uncertainty when applying the average emission factor to an individual facility, namely, that a portion of facilities within the industrial category will have emissions that are either above or below the average. However, in the absence of either monitoring data from your facility, or more accurate site-specific emission factors, EPA believes that these default emission factors can be used to make a reasonable estimation of releases.

The CDD and CDF EPA default emission factors in this guidance were developed from three primary references:

- EPA's Database of Sources of Environmental Releases of Dioxin-Like Compounds in the United States, U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington, DC 20460, EPA/600/P-

98/002B, September, 2000.

- The Inventory of Sources of Dioxin in the United States, U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington, DC 20460, EPA/600/P-98/002Aa.
- Estimating Exposure to Dioxin-Like Compounds; Volume 2: Sources of Dioxin-Like Compounds in the United States, EPA/600/)-00/001, Draft Final, September, 2000.

The most recent versions of the first two documents above can be found at:

<https://www.epa.gov/dioxin/inventory-dioxin-sources-and-environmental-releases>

When researching emission factors in Approach 2 (above), the owner and operator of a reporting facility may elect to use emission factors developed for sources other than those listed in this guidance, for example, medical waste incinerators. The owner/operator of such a facility is encouraged to review sources and releases of dioxin-like compounds contained in EPA's Database (listed above) in order to assist in the selection of more appropriate emission factors.

## **Section 2.2. Consideration of Non-Detects**

When detected in emissions and effluents from facilities, dioxin and dioxin-like compounds are found in minute quantities, e.g., one part-per trillion (1 ppt) or less, and as mixtures of dioxin and the dioxin-like compounds. Detection is with high resolution gas chromatography combined with high resolution mass spectrometry. For example, EPA Method 1613 (USEPA, 1994a) (used to quantify CDDs and CDFs in wastewater, solids, air, and tissue samples) can reliably detect these compounds at or below one part per trillion (i.e., 10 parts per quadrillion (ppq) in water; 1 ppt in solid waste). This presents a challenge in terms of interpretation of results in which a CDD/CDF compound is reported by the analytical laboratory as 'Not Detected' (shown as the abbreviation 'ND' on lab sheets).

Even with these extremely low levels of detectability with current laboratory methods, it is not possible to know with certainty if 'not detected' (ND) is actually zero (i.e., that dioxin and dioxin-like compounds are not present in the sample) or if dioxin and dioxin-like compounds really are present in the sample at some concentration below the minimal detection limit (MDL). The monitoring data and emission factors determined for your facility should be reported in a manner consistent with the methods and procedures that EPA has developed for determining if these compounds are present in various industrial processes. For example, EPA Method 1613 (USEPA, 1994a) indicates that laboratory results below the minimum detection level should be reported as not detected (ND) or as required by the regulatory authority. For purposes of threshold determinations and the reporting of releases and other waste management quantities for dioxin and dioxin-like compounds under EPCRA section 313, either with monitoring data, or by using the emission factor approach, non-detects are treated as 'zero' if that is how the method being used treats non-detects (e.g., Method 1613, Method 23). However, facilities should use their best readily available information to report, so if a facility has better information than provided by these methods then that information should be used. For example, if a facility is not

detecting dioxin or a particular dioxin-like compound using a particular method but has information that shows that they should be detecting them the facility should use this other information and it may be appropriate to estimate quantities using one half the detection limit.

If the method being used by a facility to detect dioxin and dioxin-like compounds is not an EPA approved method and the detection level being used is not as sensitive as those approved for use under EPA methods, then EPA's EPCRA section 313 guidance with regard to non-detects should be followed. This guidance states that facilities must use reasonable judgement as to the presence and amount of a listed toxic chemical based on the best readily available information. An indication that a reportable chemical is below detection is not equivalent to stating that the chemical is not present. If the reportable toxic chemical is known to be present, EPA recommends that a concentration equivalent to half the detection limit be used. Facilities should not estimate releases solely on monitoring devices, they should also rely on their knowledge of specific conditions at the plant.

### **Section 3.0. EXAMPLES OF CALCULATING EMISSIONS TO THE AIR, WATER, AND LAND**

Environmental releases of dioxin and dioxin-like compounds occur to all media air, water and land. Dioxin and dioxin-like compounds are not intentionally manufactured, they are inadvertently formed during certain manufacturing and combustion processes. In this regard, dioxin releases cannot be determined by a mass balance of your facility. Rather EPA recommends you use one of the three approaches listed in Section 2.0, above (direct measurements, or the two emission factor approaches). Section 4.0 gives EPA default emission factors for specific facilities falling within certain reporting facility industrial codes. The purpose of this section is to give examples of calculating emissions to air, water and land from your facility. In some examples the phrase “dioxin and dioxin-like compounds” may be abbreviated to “D&DLC” to save space.

#### **Section 3.1. Approach 1 - Use Actual Facility-specific Release Data**

##### **Section 3.1.1. Example of Calculating Air Releases Using Stack Monitoring Data**

*Example: Stack testing has determined that dioxin and dioxin-like compounds are detected in the stack gases at your facility at a concentration of 10 E-09 g per dry standard cubic meter of gas (10 ng/dscm). The moisture content in the stack is typically 10%. The stack gas velocity is typically 8.0 m/s. The diameter of the stack is 0.3 m. Calculate the annual air release of dioxin and dioxin-like compounds from the stack of your facility.*

##### **Step 1. Calculate volumetric flow of stack gas stream.**

$$\text{Volumetric flow} = (\text{gas velocity}) \times (\text{internal area of stack})$$

$$\text{Volumetric flow} = (\text{gas velocity}) \times \left[ (\pi) \times (\text{internal stack diameter})^2 \div 4 \right]$$

$$\text{Volumetric flow} = (8.0 \text{ m/s}) \times \left[ (\pi) \times (0.3\text{m})^2 \div 4 \right]$$

$$\text{Volumetric flow} = 5.7 \text{ m}^3/\text{s}$$

##### **Step 2. Correct volumetric flow for moisture content in stack gas stream**

*Stack gases may contain large amounts of water vapor. The concentration of the chemical in the exhaust is often presented on a ‘dry gas’ basis. For an accurate release rate, correct the stack or vent gas flow rate in Step 1 for the moisture content in your facility’s stack gas. This is done simply by multiplying the volumetric flow in Step 1 by the term (1 - fraction of water vapor). The dry gas volumetric flow rate can then be multiplied by the concentration of dioxin and dioxin-like compounds measured in the stack gases (see Step 3).*

*Dry volumetric flow = (volumetric flow) x (1 - fraction of water)*  
*Dry volumetric flow (corrected) = (5.7 m<sup>3</sup>/s) x (1 - 0.10) = 5.13 m<sup>3</sup>/s*

**Step 3. Estimate annual stack emissions to air.**

$$R_{air} = C \times V \times CF \times H \times \{ \text{units conversion factor} \}$$

Where:

- R<sub>air</sub>* = Annual release of dioxin and dioxin-like compounds to air (g/yr)
- C* = Combustion flue gas concentration of D&DLC (ng/dry standard cubic meter)
- V* = Hourly 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 on an annual basis (e.g., 0.85)
- H* = Total hours in a year (8,760 hr/yr)

$$R_{air} = (10 \text{ ng/dscm}) \times (5.13 \text{ dscm/s}) \times (3600 \text{ s/hr}) \times (8760 \text{ hr/yr}) \times (0.85) \times (g/10^9 \text{ ng})$$

$$R_{air} = 1.38 \text{ g/yr}$$

**Section 3.1.2. Example of Calculating Water Releases Using NPDES Monitoring Data**

*Example: Your facility is subject to NPDES permits for the discharge of dioxin and dioxin-like compounds into surface waters. You are required to conduct periodic monitoring of the effluent discharge from your facility. In this example, quarterly samples were taken to be analyzed for the content of dioxin and dioxin-like compounds. Each sample was an hourly, flowrate-based composite taken for one day to be representative of the discharge for that day. The total effluent volume for that day was also recorded. Your facility operates 350 days/year. The following data were collected on each sample day.*

<b>Quarter sample number</b>	<b>Discharge flow rate (10<sup>6</sup> gal/day)</b>	<b>Dioxin and dioxin-like compounds concentration (picograms per liter (pg/L))</b>
<i>1</i>	<i>20</i>	<i>10</i>
<i>2</i>	<i>20</i>	<i>10</i>
<i>3</i>	<i>40</i>	<i>10</i>
<i>4</i>	<i>100</i>	<i>10</i>

To calculate the amount of dioxin and dioxin-like compounds discharged on each sample day, the concentration of dioxin and dioxin-like compounds in the discharge is multiplied by the discharge flow rate for that day, as shown below for the first quarter sample.

**Step 1: Calculate the amount of dioxin and dioxin-like compounds discharged per day from each day of sampling.**

Amount of dioxin and dioxin-like compounds/day = (daily effluent flow rate) x (dioxin and dioxin-like compounds concentration in effluent). From the table above, the calculation of daily dioxin and dioxin-like compounds effluent discharge for the first sampling quarter is:

$$\text{First Quarter Discharge} = (10 \text{ pg/L}) \times (1 \text{ g}/10^{12} \text{ pg}) \times (3.8 \text{ L/gal}) \times (20 \times 10^6 \text{ gal/day})$$

$$\text{First Quarter Discharge} = 0.00076 \text{ g dioxin and dioxin-like compounds/day}$$

**Step 2: Find the average amount of dioxin discharged in effluent/day**

Using the same equation, the second, third and fourth quarter dioxin and dioxin-like compounds monitoring events are calculated to be 0.00076 g/day; 0.0015 g/day; and 0.0038 g/day, respectively. Then the average daily dioxin and dioxin-like compounds discharge rate for all monitoring events at this facility is:

$$\text{Average daily discharge} = [(0.00076 + 0.00076 + 0.0015 + 0.0038) / 4 \text{ sampling periods}] \text{ g/day}$$

$$\text{Average daily dioxin and dioxin-like compounds discharge} = 0.0017 \text{ g/day}$$

**Step 3 Calculate the annual discharge of dioxin to surface waters**

Your facility operates 350 days/year. The estimated annual discharge of dioxin and dioxin-like compounds is calculated as follows:

$$\text{Annual Discharge of D\&DLC to Surface Water} = (350 \text{ day/yr}) \times (0.0017 \text{ g/day})$$

$$\text{Annual Dioxin and Dioxin-like Compounds Discharge to Surface Water} = 0.6 \text{ g/yr}$$

**Section 3.1.3. Example of Estimating Releases to Land**

Under EPCRA section 313, the disposal of toxic chemicals in on-site landfills constitutes a release to land. Waste contaminated with dioxin and dioxin-like compounds may be placed in a RCRA Subtitle C landfill for disposal. The following is an example of calculating the annual quantity of dioxin and dioxin-like compounds disposed in a RCRA Subtitle C landfill.

*Example: Land disposal of sludge. Your facility generates approximately 1 kg of dry sludge per 4000 L of wastewater treated at the facility's on-site industrial wastewater treatment plant. The facility operations produce approximately 100 million L of wastewater per day. Monitoring results indicate that the sludge, on average, contains approximately 3 ng dioxin and dioxin-like compounds per kg dry sludge produced. All of the sludge from your facility is placed in an on-site RCRA Subtitle C landfill. The facility operates 350 days per year. What is the annual amount of dioxin and dioxin-like compounds released to land from your facility as a function of land disposal of the sludge contaminated with dioxin and dioxin-like compounds?*

**Step 1: Determine the amount of sludge produced per day from the wastewater treatment process.**

*Total Sludge Generated = (1 Kg sludge/4000 L wastewater) x (1 x 10<sup>8</sup> L wastewater/day)*

*Total Sludge Generated = 25,000 kg/day*

**Step 2: Determine the amount of dioxin and dioxin-like compounds contained in the sludge produced each day.**

*Total amount of D&DLC in sludge =*

*Total sludge generated x average D&DLC concentration in sludge*

*Total amount of D&DLC in sludge =*

*(25,000 kg sludge/day) x (3 ng D&DLC/kg of sludge) x (g/10<sup>9</sup> ng)*

*Total amount of dioxin and dioxin-like compounds in sludge = 0.000075 g/day*

### Step 3 Calculate the annual release of dioxin and dioxin-like compounds to land based on annual days of operation per year

*Annual release of dioxin and dioxin-like compounds to land = average daily D&DLC loading in sludge x total operating days per year.*

*Annual release of dioxin and dioxin-like compounds to land =*

$$(7.5 \times 10^{-5} \text{ g D\&DLC/day}) \times (350 \text{ operating days/yr})$$

*Annual release of dioxin and dioxin-like compounds to land = 0.03 g/yr*

### Section 3.2. Examples of Estimating Releases Using Emission Factors

You have either developed your own facility-specific emission factors or have decided to use EPA's default emission factors (refer to Section 4.0; EPA Default Emission Factors) to estimate annual releases of dioxin and dioxin-like compounds from your facility to air, land and water. Emission factors (EF) relate potential release of dioxin and dioxin-like compounds to the activity level of your facility. The units vary according to the units of measure of activity level, but usually are weight per unit weight of production or weight per unit volume related to production. A common EF for combustion processes is ng dioxin and dioxin-like compounds per kg material combusted, processed, or produced. A common EF for point source effluent discharges into surface waters is pg dioxin and dioxin-like compounds per L of wastewater discharged. A common EF for RCRA waste generated that will be disposed is pg dioxin and dioxin-like compounds per kg of waste or sludge generated. The following serve as examples of how to make calculations of annual releases of dioxin and dioxin-like compounds using either your own chosen emission factors or EPA default emission factors. In either case, the procedures are the same.

#### Section 3.2.1. Example of Estimating Air Releases

*Example: The emission factor that best fits your facility is 10 ng dioxin and dioxin-like compounds released from the stack per kg of materials processed. Each day your facility processes 25,000 kg of materials, and your facility operates 350 days per year. The emission factor is appropriate for your level of dioxin and dioxin-like compounds control. Estimate the annual release of dioxin and dioxin-like compounds from the stack of your facility.*

*Solution:*

$$R_{air} = A \times EF$$

*Where:*

*R<sub>air</sub> = annual release of dioxin and dioxin-like compounds to air; (g/yr)*

*A = material processed annually; (kg/yr)*

*EF = dioxin and dioxin-like compounds emission factor; (ng/kg)*

$$R_{air} = (25,000 \text{ kg materials/day}) \times (350 \text{ days/year}) \times (10 \text{ ng D\&DLC/kg materials}) \times (g/10^9 \text{ ng})$$

$$R_{air} = 0.09 \text{ g dioxin and dioxin-like compounds/year}$$

### Section 3.2.2. Example of Estimating Water Releases

*Example: Your facility discharges 100 million gallons per day of treated wastewater into surface water. The emission factor you have found to be most appropriate for your facility is 10 pg dioxin and dioxin-like compounds per liter of wastewater discharged. The emission factor reflects the level of dioxin and dioxin-like compounds control that is occurring at your facility. Your facility operates 365 days each year. Estimate the annual release of dioxin and dioxin-like compounds to surface water.*

*Solution:*

$$R_{water} = (100 \times 10^6 \text{ gal wastewater/day}) \times (3.78 \text{ L/gal}) \times (365 \text{ days/yr}) \\ \times (10 \text{ pg D\&DLC/L wastewater}) \times g/10^{12} \text{ pg}$$

$$R_{water} = 1.4 \text{ g dioxin and dioxin-like compounds/y}$$

### Section 3.2.3. Example of Estimating Releases to Land

*Example: In the example above, the wastewater treatment plant process generates 1 kg of dry sludge per 5000 L of wastewater treated. The wastewater treatment process removes 50% of the dioxin and dioxin-like compounds from the wastewater prior to discharging wastewater into surface water. All of the sludge generated at your facility is placed in an on-site RCRA Subtitle C landfill. Calculate how much dioxin and dioxin-like compounds are released to land at your facility.*

**Step 1. Determine the amount of sludge generated each day at your facility.**

$$\text{Sludge generated} = (\text{sludge generation rate per L wastewater}) \times (\text{wastewater per day})$$

$$\text{Sludge generated} = (1 \text{ Kg sludge/5000 L wastewater}) \times (3.78 \times 10^8 \text{ L wastewater/day})$$

$$\text{Sludge generated} = 7.56 \times 10^4 \text{ kg/day}$$

## **Step 2. Estimate the Emission Factor (EF) for dioxin and dioxin-like compounds in the sludge**

If it is assumed that all the dioxin and dioxin-like compounds that are removed from the wastewater during the treatment process are contained in the sludge generated from the wastewater treatment process, then the EF for sludge can be calculated as a function of dioxin and dioxin-like compounds removal efficiency from the wastewater. Thus the EF for dioxin and dioxin-like compounds in wastewater times the removal efficiency gives an approximate indication of the dioxin and dioxin-like compounds EF for sludge at your facility. In the following calculation, assume the density of sludge = 500 g/ L.

$$EF_{sludge} = [EF_{wastewater} \times (1 - \text{fraction D\&DLC removed})] \times (\text{density of sludge}) \times (\text{units conversion factors})$$

$$EF_{sludge} = [(10 \text{ pg D\&DLC/L wastewater}) \times (1 - 0.5)] \times (1 \text{ L/500 g}) \times (10^3 \text{ g/kg})$$

$$EF_{sludge} = 10 \text{ pg dioxin and dioxin-like compounds/kg}$$

## **Step 3. Calculate the annual release of dioxin and dioxin-like compounds to land**

$$R_{land} = (\text{quantity sludge/day}) \times (EF_{sludge}) \times (\text{operating days/year})$$

$$R_{land} = (7.56 \times 10^4 \text{ kg sludge/day}) \times (10 \text{ pg D\&DLC/kg sludge}) \times (g/10^{12} \text{ pg}) \times (365 \text{ days/year})$$

$$R_{land} = 3 \times 10^{-4} \text{ g dioxin and dioxin-like compounds/year}$$

## Section 4.0. FACILITY-SPECIFIC EPA DEFAULT EMISSION FACTORS

EPA is providing default emission factors for facilities to use, at their discretion, in reporting annual releases and other waste management quantities of dioxin and dioxin-like compounds. You are encouraged, however, to use site-specific information on releases from your facility. EPA recognizes that emissions and environmental release data are not available in most cases. This guidance is providing a series of ‘look-up’ tables to assist you in meeting the requirements of annually reporting releases of dioxin and dioxin-like compounds. Information is limited to those source categories for which EPA believes sufficient information is available to develop default emission factors that can be used to make reasonable estimations of releases. The documentation for the derivation of the emission factors can be found in three EPA references:

- EPA’s Database of Sources of Environmental Releases of Dioxin-Like Compounds in the United States, U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington, DC 20460, EPA/600/P-98/002B, September, 2000.
- The Inventory of Sources of Dioxin in the United States, U.S. Environmental Protection Agency, National Center for Environmental Assessment, Office of Research and Development, Washington, DC 20460, EPA/600/P-98/002Aa.
- Estimating Exposure to Dioxin-Like Compounds; Volume 2: Sources of Dioxin-Like Compounds in the United States, EPA/600/)-00/001, Draft Final, September, 2000.

The most recent versions of the first two documents above can be found at:

<https://www.epa.gov/dioxin/inventory-dioxin-sources-and-environmental-releases>

In applying these default emission factors, you are encouraged to read the summary description provided for the facilities that were used to derive the default emission factors. Facilities should use those emission factors that match as closely as practical the class type and pollution control systems of your facility. Although EPA’s default emission factors are arithmetic averages of environmental releases from tested facilities, EPA recognizes that these tested facilities may not be an ideal match to your facility. The decision to use EPA default emission factors is best left to the operator of the facility. This guidance is intentionally made to be flexible in the use and selection of emissions of dioxin and dioxin-like compounds that are most representative of emissions from your facility. All of the emission factors contained in the tables in this section are for controlled conditions.

In all of the emission factors tables the emission factor for the dioxin and dioxin-like compounds category is equal to the sum of the emission factors for the 7 dibenzo-p-dioxins (CDDs) covered by the category and the 10 dibenzofurans (CDFs) covered by the category. Thus,

$$\sum \text{Dioxin and dioxin-like compounds} = \sum \text{CDDs} + \sum \text{CDFs}$$

## **Section 4.1. Pulp and Paper Mills and Lumber and Wood Products**

### **Section 4.1.1. Applicability**

The following SIC Codes are included within this category (a crosswalk with NAICS codes is available at: <https://www.census.gov/eos/www/naics/concordances/concordances.html>):

I. SIC Code 2611 Pulp Mills: Establishments primarily engaged in manufacturing pulp from wood or from other materials, such as rags, linters, wastepaper, and straw. Establishments engaged in integrated logging and pulp mill operations are classified according to the primary products shipped.

Establishments engaged in integrated operations of producing pulp and manufacturing paper, paperboard, or products thereof are classified in Industry 2621 if primarily shipping paper or paper products; in Industry 2631 if primarily shipping paperboard or paperboard products; and in Industry 2611 if primarily shipping pulp.

II. 2621 Paper Mills: Establishments primarily engaged in manufacturing paper from woodpulp and other fiber pulp, and which may also manufacture converted paper products. Establishments primarily engaged in integrated operations of producing pulp and manufacturing paper are included in this industry if primarily shipping paper or paper products. Establishments primarily engaged in manufacturing converted paper products from purchased paper stock are classified in Industry Group 265 or Industry Group 267.

III. 2400 Lumber and Wood Products, Except Furniture: Establishments primarily engaged in cutting timber and pulpwood; merchant sawmills, lath mills, shingle mills, cooperage stock mills, planing mills, and plywood mills and veneer mills engaged in producing lumber and wood basic materials. Also included within this SIC code are establishments engaged in manufacturing finished articles made entirely or mainly of wood or related materials. Major Group 24 includes Industry Groups 241, 242, 243, 244, 245, and 249. Furniture and office and store fixtures are classified in Major Group 25. Woodworking in connection with construction, in the nature of reconditions and repair, or performed to individual order, is classified in nonmanufacturing industries.

#### Industry Group 241

2411 Logging

#### Industry Group 242

2421 Sawmills and Planing Mills

2431 Millwork

2434 Wood Kitchen Cabinets

2435 Hardwood Veneer and Plywood

2436 Softwood Veneer and Plywood

#### Industry Group 244

2441 Nailed and Lock Corner Wood Boxes and Shook

2448 Wood Pallets and Skids

2449 Wood Containers

- Industry Group 245
  - 2451 Mobile Homes
  - 2452 Prefabricated Wood Buildings and Components Industry
- Group 249
  - 2491 Wood Preserving
  - 2493 Reconstituted Wood Products 2499
  - Wood Products

### Section 4.1.2. Emission Factors for Releases to Water From Bleached Chemical Pulp Mills

On April 15, 1998 and August 7, 1998, EPA promulgated final effluent standards (Federal Register, 1998) under the Clean Water Act for pulp and paper mills (63 FR 18504-18751, and 63 FR 42238-42240). Mills subject to regulation are pulp mills and integrated mills (mills that manufacture pulp and paper/paperboard), that chemically pulp wood fiber (using kraft, sulfite, soda, or semi-chemical methods); that produce pulp secondary fiber; pulp non-woody fiber; and mechanically pulp wood fiber. The regulations established dioxin discharge limits for bleached chemical pulp mills. In reporting releases of dioxin and dioxin-like compounds to surface waters, the facility may use the EPA default emission factors in Table 4-1, which were developed for bleached chemical pulp mills. The data were generated at a series of eight bleached chemical pulp mills prior to promulgation of the effluent standards.

**Table 4-1. Average Emission Factors (pg/L) for Estimating Wastewater Discharges of Dioxin and Dioxin-like Compounds into Surface Water From Bleached Chemical Pulp Mills**

CDD	Mean Emission Factor (pg/L)	CDF	Mean Emission Factor (pg/L)
2,3,7,8-TCDD	1.2	2,3,7,8-TCDF	2.3
1,2,3,7,8-PeCDD	0	1,2,3,7,8-PeCDF	0
1,2,3,4,7,8-HxCDD	0	2,3,4,7,8-PeCDF	0
1,2,3,6,7,8-HxCDD	0	1,2,3,4,7,8-HxCDF	0
1,2,3,7,8,9-HxCDD	0	1,2,3,6,7,8-HxCDF	0
1,2,3,4,6,7,8-HpCDD	3.2	1,2,3,7,8,9-HxCDF	0
1,2,3,4,6,7,8,9-OCDD	99.0	2,3,4,6,7,8-HxCDF	0
		1,2,3,4,6,7,8-HpCDF	0
		1,2,3,4,7,8,9-HpCDF	0
		1,2,3,4,6,7,8,9-OCDF	0
$\Sigma$ CDDs	103.4 pg /L	$\Sigma$ CDFs	2.3 pg /L
$\Sigma$ Dioxin and dioxin-like compounds*	105.7 pg/L		

Source: Gillespie, 1997; \*  $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

### Section 4.1.3. Emission Factors for Releases to Land from Bleached Chemical Pulp Mills

The conventional wastewater treatment of effluents results in the generation of wastewater sludge. If your facility applies the sludge to land, or places it in a RCRA Subtitle C landfill for disposal, then the default emission factors for bleached chemical pulp mills in Table 4-2 apply. These emission factors are based on data from a series of the same bleached chemical pulp mills referenced in section 4.1.2.

**Table 4-2. Average Emission Factors (ng/kg) for Land Disposal of Dioxin and Dioxin-like Compounds in Wastewater Sludge from Bleached Chemical Pulp Mills.**

CDD	Mean Emission Factor (ng/kg)	CDF	Mean Emission Factor (ng/kg)
2,3,7,8-TCDD	0.8	2,3,7,8-TCDF	6.2
1,2,3,7,8-PeCDD	0	1,2,3,7,8-PeCDF	0
1,2,3,4,7,8-HxCDD	0.5	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	2.3	1,2,3,4,7,8-HxCDF	0
1,2,3,7,8,9-HxCDD	1.6	1,2,3,6,7,8-HxCDF	0
1,2,3,4,6,7,8-HpCDD	41.4	1,2,3,7,8,9-HxCDF	0
1,2,3,4,6,7,8,9-OCDD	445.0	2,3,4,6,7,8-HxCDF	0.5
		1,2,3,4,6,7,8-HpCDF	1.2
		1,2,3,4,7,8,9-HpCDF	0
		1,2,3,4,6,7,8,9-OCDF	0
$\Sigma$ CDDs	491.6 ng /kg	$\Sigma$ CDFs	8.4 ng /kg
$\Sigma$ Dioxin and dioxin-like compounds*	500 ng/kg		

Source: Gillespie, 1997; \*  $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

### Section 4.1.4. Emission Factors for Releases to Air from Pulp Mill or Lumber and Wood Products Facilities

Wood waste and bark produced from processing timber at a pulp mill or lumber and wood products facility are burned in the facilities' bark and/or wood-waste boilers (NCASI, 1995). This wood waste can produce CDDs/CDFs during combustion. If your lumber and wood products industry facility burns wood waste and bark, then the default emission factors in Table 4-3 apply.

**Table 4-3. Average Emission Factors (ng/kg) for Air Releases of Dioxin and Dioxin-like Compounds from the Combustion of Wood Waste and Bark (as fired) at Pulp Mill or Lumber and Wood Product Industry Facility Boilers.**

CDD	Mean Emission Factor (ng/kg)	CDF	Mean Emission Factor (ng/kg)
2,3,7,8-TCDD	0.005	2,3,7,8-TCDF	0.104
1,2,3,7,8-PeCDD	0.005	1,2,3,7,8-PeCDF	0.022
1,2,3,4,7,8-HxCDD	0.012	2,3,4,7,8-PeCDF	0.020
1,2,3,6,7,8-HxCDD	0.050	1,2,3,4,7,8-HxCDF	0.070
1,2,3,7,8,9-HxCDD	0.035	1,2,3,6,7,8-HxCDF	0.043
1,2,3,4,6,7,8-HpCDD	0.300	1,2,3,7,8,9-HxCDF	0.036
1,2,3,4,6,7,8,9-OCDD	1.200	2,3,4,6,7,8-HxCDF	0.004
		1,2,3,4,6,7,8-HpCDF	0.274
		1,2,3,4,7,8,9-HpCDF	0.081
		1,2,3,4,6,7,8,9-OCDF	0.187
$\sum$ CDDs	1.6 ng /kg	$\sum$ CDFs	0.84 ng /kg
$\sum$ Dioxin and dioxin-like compounds*	2.4 ng/kg		

Source: NCASI (1995); \*  $\sum$  Dioxin and dioxin-like compounds =  $\sum$  CDDs +  $\sum$  CDFs

## Section 4.2. Secondary Smelting and Refining of Nonferrous Metals

### Section 4.2.1. Applicability

SIC Code 3341, Secondary Smelting and Refining of Nonferrous Metals, include establishments primarily engaged in recovering nonferrous metals and alloys from new and used scrap and or in producing alloys from purchased refined metals (a crosswalk with NAICS codes is available at: <https://www.census.gov/eos/www/naics/concordances/concordances.html>). This industry includes establishments engaged in both the recovery and alloying of precious metals. Plants engaged in the recovery of tin through secondary smelting and refining, as well as by chemical processes, are included in this industry. Establishments primarily engaged in assembling, sorting, and breaking up scrap metal, without smelting and refining, are classified in Wholesale Trade, Industry 5093. Applicable facilities include:

- Aluminum smelting and refining, secondary
- Copper smelting and refining, secondary
- Lead smelting and refining, secondary
- Nonferrous metal smelting and refining, secondary
- Recovering and refining of nonferrous metals
- Secondary refining and smelting of nonferrous metals

## Section 4.2.2. Secondary Aluminum Smelters

Stack tests from five secondary aluminum facilities (described below) were used by EPA to derive mean air emission factors of dioxin and dioxin-like compounds. Secondary aluminum smelters reclaim aluminum from scrap containing aluminum. This recycling involves two processes: pre-cleaning and smelting. Both processes may produce CDD/CDF emissions.

Pre-cleaning processes involve sorting and cleaning scrap to prepare it for smelting. Cleaning processes that may produce CDD/CDF emissions use heat to separate aluminum from contaminants and other metals; these techniques are roasting and sweating. Roasting uses rotary dryers with a temperature high enough to vaporize organic contaminants, but not high enough to melt aluminum. An example of roasting is the delacquering and processing of used beverage cans. Sweating involves heating aluminum-containing scrap metal to a temperature above the melting point of aluminum, but below the melting temperature of other metals such as iron and brass. The melted aluminum trickles down and accumulates in the bottom of the sweat furnace and is periodically removed (U.S. EPA, 1997).

After pre-cleaning, the treated aluminum scrap is smelted and refined. This usually takes place in a reverberatory furnace. Once smelted, flux is added to remove impurities. The melt is "demagged" to reduce the magnesium content of the molten aluminum by the addition of chlorine gas. The molten aluminum is transferred to a holding furnace and alloyed to final specifications (U.S. EPA, 1997).

CDD/CDF emissions to air have been measured at five U.S. secondary aluminum operations. These facilities were tested in 1995. The tests were conducted by EPA in conjunction with the Aluminum Association for the purpose of identifying emission rates from facilities with potentially maximum achievable control technology (MACT)-grade operations and air pollution control device (APCD) equipment.

The first facility tested in 1995 was a top charge melt furnace (Advanced Technology Systems, Inc., 1995). During testing, the charge material to the furnace was specially formatted to contain no oil, paint, coatings, rubber, or plastics (other than incidental amounts). The CDD/CDF emissions from such a clean charge, 0.26 ng toxic equivalents (TEQ)/kg charge material, would be expected to represent the low-end of the normal industry range.

The second facility operates a sweat furnace to pre-clean the scrap and a reverberatory furnace to smelt the pre-cleaned aluminum (U.S. EPA, 1995). Stack emissions are controlled by an afterburner operated at 1,450°F.

The third facility employs a crusher/roasting dryer as a pre-cleaning step followed by a reverberatory furnace (Galson Corporation, 1995). The emissions from the two units are vented separately. The exhaust from the crusher/dryer is treated with an afterburner and a baghouse. The exhaust from the furnace passes through a baghouse with lime injection.

The fourth facility operates a scrap roasting dryer followed by a sidewall reverberatory furnace (Roy Weston, 1996). The emissions from the two units are vented separately. Exhaust from the dryer passes through an afterburner and a lime-coated baghouse. The exhaust from the furnace passes through a lime-coated baghouse.

The fifth facility is a dryer/delacquarer secondary aluminum facility tested by Commonwealth Aluminum Corporation (1995). The results of this test were submitted to EPA as part of the public comments by the industry in association with development of the MACT standard.

Table 4-4 summarizes average default emission factors (ng/kg scrap aluminum processed) for estimating air releases of dioxin and dioxin-like compounds from secondary aluminum smelters. For the default emission factor, EPA is recommending 44.55 ng dioxin and dioxin-like compounds emitted per kg of aluminum scrap processed. This is based on an arithmetic average of the five tested facilities presented in the Table. As an alternative to using this default emission factor, the owner or operator of secondary aluminum facilities may review the individual test reports supporting the development of the table (see references), and, based on good engineering judgement, decide the most appropriate emission factors for your facility. Defaults are given here in the context of providing an option for estimating air releases from secondary aluminum smelters.

**Table 4-4. Average Emission Factors (ng/kg scrap aluminum processed) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Secondary Aluminum Smelters**

Congener	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 1)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 2)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 3)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 4)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 5)
2,3,7,8-TCDD	ND	0.13	0.51	0.25	0.01
1,2,3,7,8-PeCDD	0.02	0.39	1.19	0.75	0.02
1,2,3,4,7,8-HxCDD	0.05	0.24	1.35	0.53	0.02
1,2,3,6,7,8-HxCDD	0.13	0.86	1.52	0.65	0.03
1,2,3,7,8,9-HxCDD	0.15	1.26	2.51	1.29	0.05
1,2,3,4,6,7,8-HpCDD	0.51	7.67	2.60	2.84	0.1
OCDD	0.42	14.97	1.01	NA	NA
2,3,7,8-TCDF	0.44	0.74	14.20	5.50	0.08
1,2,3,7,8-PeCDF	0.06	1.51	10.47	1.90	0.07
2,3,4,7,8-PeCDF	0.17	2.44	11.06	3.18	0.12
1,2,3,4,7,8-HxCDF	0.32	2.44	21.84	4.65	0.16
1,2,3,6,7,8-HxCDF	0.11	2.69	7.10	1.48	0.06
1,2,3,7,8,9-HxCDF	0.02	1.02	0.47	0.08	0.01
2,3,4,6,7,8-HxCDF	0.30	3.82	7.09	1.87	0.08
1,2,3,4,6,7,8-HpCDF	0.07	11.39	14.61	2.97	0.17
1,2,3,4,7,8,9-HpCDF	0.03	5.50	1.21	0.24	0.04
OCDF	0.30	30.40	3.15	1.04	0.06
∑ Dioxin and Dioxin-Like Compounds	3.1	87.47	101.89	29.22	1.08
Mean emission factors of dioxin and dioxin-like compounds	44.55				

TEQ calculations assume not-detected values are zero.

NA= Not available.

ND = Not detected (value in parenthesis is the emission at the detection limit).

Sources: Ref. 1: Advanced Technology Systems, Inc. (1995)

Ref. 2: U.S. EPA (1995h)

Ref. 3: Galson Corporation (1995)

Ref. 4: Roy Weston, Inc. (1996)

Ref. 5: Commonwealth Aluminum Corp (1995)

### Section 4.2.3. Secondary Lead Smelters

The secondary lead smelting industry produces elemental lead through the chemical reduction of lead compounds in a high temperature furnace (1,200 to 1,260°C). Smelting is performed in reverberatory, blast, rotary, or electric furnaces. Blast and reverberatory furnaces are the most common types of smelting furnaces used by the 23 facilities that comprise the current secondary lead smelting industry in the United States. Of the 45 furnaces at these 23 facilities, 15 are reverberatory furnaces, 24 are blast furnaces, five are rotary furnaces, and one is an electric furnace. The one electric furnace and 11 of the 24 blast furnaces are co-located with reverberatory furnaces, and most share a common exhaust and emissions control system (U.S. EPA, 1994b).

Furnace charge materials consist of lead-bearing raw materials, lead-bearing slag and drosses, fluxing agents (blast and rotary furnaces only), and coke. Scrap motor vehicle lead-acid batteries represent about 90 percent of the lead-bearing raw materials at a typical lead smelter. Fluxing agents consist of iron, silica sand, and limestone or soda ash. Coke is used as fuel in blast furnaces and as a reducing agent in reverberatory and rotary furnaces. Organic emissions from co-located blast and reverberatory furnaces are more similar to the emissions of a reverberatory furnace than the emissions of a blast furnace (U.S. EPA, 1994b).

Historically, many lead-acid batteries contained PVC plastic separators between the battery grids. These separators are not removed from the lead-bearing parts of the battery during the battery breaking and separation process. When the PVC is burned in the smelter furnace, the chlorine atoms are released as HCl, Cl<sub>2</sub>, and chlorinated hydrocarbons (Federal Register, 1995d). The source of CDDs/CDFs at secondary lead smelters is the PVC separator (U.S. EPA, 1995c). In 1990, about 1 percent of scrap batteries processed at lead smelters contained PVC separators. In 1994, less than 0.1 percent of scrap batteries contained PVC separators. This trend is expected to continue because no U.S. manufacturer of lead-acid automotive batteries currently uses PVC in production (U.S. EPA, 1995c; Federal Register, 1995d).

The total current annual production capacity of the 23 companies currently comprising the U.S. lead smelting industry is 1.36 million metric tons. Blast furnaces not co-located with reverberatory furnaces account for 21 percent of capacity (or 0.28 million metric tons). Reverberatory furnaces and blast and electric furnaces co-located with reverberatory furnaces account for 74 percent of capacity (or 1.01 million metric tons). Rotary furnaces account for the remaining 5 percent of capacity (or 0.07 million metric tons). Actual production volume statistics by furnace type are not available. However, if it is assumed that the total actual production volume of the industry, 0.97 million metric tons in 1995 (U.S. Geological Survey, 1997a) and 0.72 million metric tons in 1987 (U.S. EPA, 1994a), are reflective of the production capacity breakdown by furnace type, then the estimated actual production volumes of blast furnaces (not co-located), reverberatory and co-located blast/electric and reverberatory furnaces, and rotary furnaces were 0.20, 0.72, and 0.05 million metric tons, respectively, in 1995, and 0.15, 0.53, and 0.04 million metric tons, respectively, in 1987. In 1987, the industry consisted of 24 facilities.

CDD/CDF emission factors can be estimated for lead smelters based on the results of emission tests performed by EPA at three smelters (a blast furnace, a co-located blast/reverberatory furnace, and a rotary kiln furnace) (U.S. EPA, 1992e; 1995d; 1995e). The air pollution control systems at the three tested facilities consisted of both baghouses and scrubbers. Congener-specific measurements were made at the exit points of both APCD exit points at each facility. Table 4-5 presents the congener emission factors from the baghouse and the scrubber for each site. Although all 23 smelters employ baghouses, only 9 employ scrubber technology.

**Table 4-5. Average Emission Factors (ng/kg) for Estimating Annual Releases of Dioxin and Dioxin-Like Compounds from Secondary Lead Smelters**

CDD/CDF Congener	Blast Furnace (ng/kg lead produced)		Blast/reverb (ng/kg lead produced)		Rotary kiln (ng/kg lead produced)	
	<i>before scrubber</i>	<i>after scrubber</i>	<i>before scrubber</i>	<i>after scrubber</i>	<i>before scrubber</i>	<i>after scrubber</i>
2,3,7,8-TCDD	2.11	0.25	0.00	0.00	0.10	0.24
1,2,3,7,8-PeCDD	0.99	0.03	0.00	0.00	0.01	0.00
1,2,3,4,7,8-HxCDD	0.43	0.00	0.00	0.00	0.00	0.00
1,2,3,6,7,8-HxCDD	0.99	0.03	0.00	0.00	0.00	0.00
1,2,3,7,8,9-HxCDD	1.55	0.03	0.00	0.00	0.00	0.00
1,2,3,4,6,7,8-HpCDD	2.06	0.08	0.10	0.06	0.00	0.22
1,2,3,4,6,7,8,9-OCDD	1.40	0.39	0.57	0.55	0.24	2.41
$\Sigma$ CDDs	9.53	0.81	0.67	0.61	0.35	2.87
2,3,7,8-TCDF	8.73	0.93	1.46	0.49	0.40	1.20
1,2,3,7,8-PeCDF	3.88	0.43	0.24	0.02	0.14	0.40
2,3,4,7,8-PeCDF	6.65	0.36	0.31	0.00	0.14	0.46
1,2,3,4,7,8-HxCDF	5.83	0.37	0.63	0.00	0.11	0.27
1,2,3,6,7,8-HxCDF	1.67	0.11	0.19	0.00	0.02	0.10
1,2,3,7,8,9-HxCDF	0.11	0.00	0.00	0.00	0.04	0.13
2,3,4,6,7,8-HxCDF	2.06	0.11	0.15	0.00	0.00	0.00
1,2,3,4,6,7,8-HpCDF	2.34	0.19	0.48	0.00	0.03	0.13
1,2,3,4,7,8,9-HpCDF	0.63	0.06	0.00	0.00	0.00	0.00
1,2,3,4,6,7,8,9-OCDF	1.39	0.18	0.29	0.00	0.00	0.00
$\Sigma$ CDFs	33.29	2.74	3.75	0.51	0.88	2.69
$\Sigma$ Dioxin and dioxin-like compounds*	42.82	3.55	4.42	1.12	1.23	5.56

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

Facilities that employ scrubbers account for 14 percent of the blast furnace (not co-located) production capacity, 52 percent of the reverberatory and co-located furnace production capacity, and 57 percent of the rotary furnace production capacity. From the reported data, congener-specific CDD/CDF emission factors (ng /kg lead processed) for each of the three furnace configurations are presented in Table 4-5. The range reflects the presence or absence of a scrubber. Note that calculations using emission factors before scrubbers would apply towards threshold calculations since this represents amounts that have been manufactured. They can also be used to estimate the amounts that a scrubber has removed and then the amounts removed, depending on how the scrubber material is handled, should be reported in the appropriate section of the Form R.

As discussed earlier in this section, the PVC separators used historically in lead-acid batteries are believed to be the source of the CDD/CDFs observed in emissions from secondary lead smelters. PVC separators are no longer used in the United States in the manufacture of lead-acid batteries, and less than 0.1 percent of the scrap batteries in 1994 contained PVC separators (U.S. EPA, 1995c; Federal Register, 1995c). EPA predicts that by the time existing smelters demonstrate compliance in 1997 with the National Emission Standards for Hazardous Air Pollutants (NESHAP) for secondary lead smelters promulgated by EPA (Federal Register, 1995c), batteries containing PVC will only be present in the scrap battery inventory in trace amounts, resulting at most, in only trivial amounts of HCl or Cl<sub>2</sub> air emissions.

#### **Section 4.2.4. Secondary Copper Smelters/Refiners**

Secondary copper smelting is part of the scrap copper, brass, and bronze reprocessing industry. Brass is an alloy of copper and zinc; bronze is an alloy of copper and tin. Facilities in this industry fall into three general classifications: secondary smelting, ingot making, and remelting. Similar process equipment may be used at all three types of facilities, so that the distinguishing features are not immediately apparent (U.S. EPA, 1994c).

The feature that distinguishes secondary smelters from ingot makers and remelters is the extent to which pyrometallurgical purification is performed. A typical charge at a secondary smelter may contain from 30 to 98 percent copper. The secondary smelter upgrades the material by reducing the quantity of impurities and alloying materials, thereby increasing the relative concentration of copper. This degree of purification and separation of the alloying constituents does not occur at ingot makers and remelters. Feed material to a secondary copper smelter is a mixture of copper-bearing scrap comprised of such scrap as tubing, valves, motors, windings, wire, radiators, turnings, mill scrap, printed circuit boards, telephone switching gear, and ammunition casings. Non-scrap items like blast furnace slags and drosses from ingot makers or remelters may represent a portion of the charge. The secondary smelter operator uses a variety of processes to separate the alloying constituents. Some purify the scrap in the reductive atmosphere of a blast furnace. The charge may be subsequently purified in the oxidizing atmosphere of a converter. Other secondary smelters perform all purification by oxidation in top-blown rotary converters or in reverberatory furnaces (U.S. EPA, 1994c).

The ingot makers blend and melt scrap copper, brass, and bronze of various compositions to produce a specification brass or bronze ingot. When necessary, the ingot makers add ingots of other metals (e.g., zinc or tin) to adjust the metallurgy of the final product. The feed materials for ingot makers contain relatively high amounts of copper. Examples of feed materials include copper tubing, valves, brass and bronze castings, ammunition shell casings, and automobile radiators. "Fire-refined" anode copper or cathode copper may also be charged. Items such as motors, telephone switchboard scrap, circuit board scrap, and purchased slags are not used by ingot makers. The reductive step (melting in a reducing atmosphere, as in a blast furnace) that some secondary smelters employ is not used by ingot makers. Ingot makers do, however, use some of the other types of furnaces used by secondary smelters, including direct-fired converters, reverberatory furnaces, and electric induction furnaces (U.S. EPA, 1994c).

Remelting facilities do not conduct any substantial purification of the incoming feeds. These facilities typically just melt the charge and cast or extrude a product. The feeds to a remelter are generally alloy material of approximately the desired composition of the product (U.S. EPA, 1994c).

In 1991, stack testing of the rotary furnace stack emissions of a secondary smelter located in Alton, Illinois (Chemetco, Inc.) was conducted by Sverdrup Corp. (1991). The Chemetco facility uses four tap down rotary (i.e., oxidizing) furnaces. Furnace process gas emissions are controlled by a primary quencher and a venturi scrubber. The feed is relative high purity copper scrap containing minimal plastics, if any. The same manufacturing process and APCD equipment were in place in 1987 and 1995 (U.S. EPA, 1994c). This facility operated under oxidizing rather than reducing conditions and processes relatively high purity scrap, the potential for CDD/CDF formation and release is expected to be dramatically different than that of the two tested facilities reported above. The estimated emission factors derived for this site from the results in Sverdrup (1991) are presented in Table 4-6.

Although little research has been performed to define the CDD/CDF formation mechanism(s) in secondary copper smelting operations, two general observations have been made (Buekens et al., 1997). The presence of chlorinated plastics in copper scraps used as feed to the smelters is believed to increase the CDD/CDF formation. Second, the reducing or pyrolytic conditions in blast furnaces can lead to high CDD/CDF concentrations in the furnace process gases.

It should be noted that a significant amount of scrap copper is consumed by other segments of the copper industry. In 1995, brass mills and wire-rod mills consumed 886,000 metric tons of copper-base scrap; foundries and miscellaneous manufacturers consumed 71,500 metric tons (U.S. Geological Survey, 1997). As noted above, however, these facilities generally do not conduct any significant purification of the scrap. Rather, the scrap consumed is already of alloy quality and processes employed typically involve only melting, casting and extruding. Thus, the potential for formation of CDDs/CDFs is expected to be much less than the potential during secondary smelting operations.

**Table 4-6. CDD/CDF Emission Factors (ng Dioxin and Dioxin-like Compounds per kg copper scrap processed) for Secondary Copper Smelters**

Congener	Chemetco Smelting (ng/kg scrap feed)
2,3,7,8-TCDD	ND (0.05)
1,2,3,7,8-PeCDD	0.21
1,2,3,4,7,8-HxCDD	0.39
1,2,3,6,7,8-HxCDD	0.70
1,2,3,7,8,9-HxCDD	1.26
1,2,3,4,6,7,8-HpCDD	8.95
1,2,3,4,6,7,8,9-OCDD	22.45
$\Sigma$ CDDs	33.96
2,3,7,8-TCDF	2.11
1,2,3,7,8-PeCDF	1.47
2,3,4,7,8-PeCDF	2.63
1,2,3,4,7,8-HxCDF	7.30
1,2,3,6,7,8-HxCDF	2.15
1,2,3,7,8,9-HxCDF	4.06
2,3,4,6,7,8-HxCDF	0.27
1,2,3,4,6,7,8-HpCDF	11.48
1,2,3,4,7,8,9-HpCDF	2.74
1,2,3,4,6,7,8,9-OCDF	21.61
$\Sigma$ CDFs	55.82
$\Sigma$ Dioxin and dioxin-like compounds*	89.78

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

ND = Not detected (value in parenthesis is the emission at the detection limit). Source: Sverdrup (1991).

Table 4-6 is a listing of CDD/CDF default emissions factors for secondary copper smelters. In choosing the appropriate emission factor, the owner/operator is encouraged to exercise good engineering judgement to appropriately select the most suitable emission factors. Such judgement requires first-hand knowledge of your process. EPA believes that the most appropriate default emission factors are those derived from the stack testing of the Chemetco Smelting Facility as shown in Table 4-6. This is because the state-of-the-art involved in secondary copper smelting calls for the mechanical removal of plastic material prior to smelting and refining, and to use copper-laden scrap that is relatively free of organic contamination. Therefore, if your facility processes copper scrap containing a relatively high amount of plastics, then the emission factors listed in Table 4-6 are not appropriate to use as default emission factors.

## **Section 4.3. Cement Kilns**

### **Section 4.3.1. Applicability**

Kilns used in the pyroprocessing of Portland Cement clinker as defined in SIC Code 3241 (a crosswalk with NAICS codes is available at: <https://www.census.gov/eos/www/naics/concordances/concordances.html>).

### **Section 4.3.2. Summary Description / Air Emission Factors**

In the United States, the primary cement product is called Portland cement. Portland cement is a fine, grayish powder consisting of a mixture of four basic materials: limestone, silica, alumina, and iron compounds. Cement production involves heating (pyroprocessing) the raw materials (known as raw meal) to a very high temperature in a rotary (rotating) kiln to induce chemical reactions that produce a fused material called clinker. The cement clinker is further ground into a fine powder and mixed with gypsum to form the Portland cement.

The cement kiln is a large, rotating steel cylindrical furnace lined with refractory material. The kiln is aligned on a slight angle, usually a slope of 3° - 6°. This allows for the materials to pass through the kiln by gravity. The upper end of the kiln is known as the cold or back end and this is where the raw materials, or meal, is generally fed into the kiln. The lower end of the kiln is known as the “hot” end. The hot end is where the combustion of primary fuels (coal, petroleum coke, natural gas, etc.) transpires to produce a high temperature.

The cement kiln is operated in a counter-current configuration. This means that the hot combustion gases are convected up through the kiln while the raw materials are passing down toward the lower end. The rotation of the kiln induces mixing and the forward progress of mixed materials. As the meal moves through the cement kiln and is heated by the hot combustion gases, water is vaporized and pyroprocessing of materials occurs.

When operating, the cement kiln can be viewed as consisting of three temperature zones necessary to produce clinker. Zone 1 is at the upper end of the kiln where the raw meal is added. Temperatures in this zone typically range from ambient up to 600°C. In this area of the kiln, moisture is evaporated from the raw meal. The second thermal zone is known as the calcining zone. Calcining occurs when the hot combustion gases from the combustion of primary fuels dissociates calcium carbonate from the limestone to form calcium oxide. In this region of the kiln, temperatures are in a range of 600°C to 900°C. The third region of the kiln is known as the burning or sintering zone. The burning zone is the hottest region of the kiln. In this region, temperatures in excess of 1,500°C induce the calcium oxide to react with silicates, iron and aluminum in the raw materials to form clinker. The formation of clinker actually occurs near the lower end of the kiln (close to the combustion of primary fuel) where temperatures are the hottest. The chemical reactions that occur here are referred to as pyroprocessing.

The clinker that leaves the hot end of the kiln is a gray-colored, glass-hard material comprised

of dicalcium silicate, tricalcium silicate, calcium aluminate, and tetracalcium aluminoferrite. At this point, the clinker has a temperature of about 1,100° C. The hot clinker is then transferred into the clinker cooler. Once cooled, the clinker is ground into a fine powder and mixed with gypsum to produce Portland cement.

Cement kilns are either wet or dry processes. In the wet process, the raw materials are ground and mixed with water to form a slurry. The meal-water slurry is fed into the kiln through a pump. A greater amount of heat energy is needed in the wet process to evaporate the additional water.

In the dry process, the raw meal is ground to a fine, dry powder prior to entering the kiln. There are three types of dry processes: long-dry, preheater, and preheater/precalciner. Long dry kilns are similar to wet kilns, with the exception of the dry state of the raw materials. In preheater kilns, the raw material is heated prior to entering the kiln. This allows for a shorter kiln and lower combustion fuel use. Precalciners take this a step further by heating the raw feed to a level at which partial calcination takes place prior to entering the kiln. A typical preheater/precalciner kiln consists of a vertical tower containing a series of cyclone-type vessels. Raw meal is added at the top of the tower, and hot kiln exhaust flue gases from the kiln operation are used to preheat the meal prior to being introduced into the kiln. Preheating and precalcining the meal has the advantage of lowering fuel consumption of the kiln.

There are also two primary types of air pollution control devices (APCDs) for the kiln: fabric filters and electrostatic precipitators (ESPs). Either of these can be used on any of the four process types.

Cement manufacturing is an energy intensive manufacturing process. Fossil fuels are the primary sources of fuel. In addition, 15 cement plants in the U.S. currently supplement their fuel needs through the use of energy-bearing hazardous waste. For the last ten years, these facilities have been regulated by the Resource Conservation and Recovery Act's (RCRA) Boiler and Industrial Furnace (BIF) rules. As a result, a database has been developed characterizing emissions from these facilities. Testing and additional studies have contributed significantly to our understanding of dioxin formation in cement plants.

In developing Maximum Achievable Control Technology (MACT) standards for cement plants, EPA "considered both hazardous waste burning cement kiln and non-hazardous waste burning cement kiln data together because both data sets are adequately representative of general dioxin/furan behavior and control in either type of kiln. This similarity is based on our engineering judgement that hazardous waste burning does not have an impact on dioxin/furan formation, dioxin/furan is formed post-combustion." (See 64 FR 52876) APCD air inlet temperature (and the time that the air takes to enter the device) in conjunction with other site-specific elements is the determining factor.

On June 14, 1999, EPA published a National Emission Standard for Hazardous Air Pollutants (NESHAP) for the Portland cement industry in the Federal Register (64 FR 31898). In addition, on September 30, 2000, EPA published a National Emission Standard for Hazardous Air Pollutants

(NESHAP) for hazardous waste combustors (including cement kilns that recover energy from hazardous wastes) in the Federal Register (64 FR 52828). These rules require, among other things, that all cement plants periodically conduct dioxin/furan testing.

The EPA source emissions data base contains test reports of CDD/CDF emissions from 15 cement kilns not burning hazardous waste. The average CDD/CDF emission factors displayed in Table 4-7 are derived as an average from these test data. These default emission factors are more appropriate for facilities tested in 1998, and do not reflect changes that have occurred since that time. As an operator/owner of a facility, you may elect to use more current information in the development of an emission factor, or you may elect to use the EPA default. If you elect to use more current emission factors, then you will be using Approach 2 (Section 2.1.2) to derive your emission estimate appropriate for your facility.

**Table 4-7. Average Emission Factors (ng/kg of cement clinker produced) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Cement Kilns Not Combusting Hazardous Waste as Supplemental Fuel**

CDD Congener	Emission Factor (ng/kg clinker)	CDF Congener	Emission Factor (ng/kg clinker)
2,3,7,8-TCDD	0.012	2,3,7,8-TCDF	0.729
1,2,3,7,8-PeCDD	0.034	1,2,3,7,8-PeCDF	0.102
1,2,3,4,7,8-HxCDD	0.028	2,3,4,7,8-PeCDF	0.224
1,2,3,6,7,8-HxCDD	0.042	1,2,3,4,7,8-HxCDF	0.185
1,2,3,7,8,9-HxCDD	0.048	1,2,3,6,7,8-HxCDF	0.054
1,2,3,4,6,7,8-HpCDD	0.426	1,2,3,7,8,9-HxCDF	0.007
1,2,3,4,6,7,8,9-OCDD	0.692	2,3,4,6,7,8-HxCDF	0.082
		1,2,3,4,6,7,8-HpCDF	0.146
		1,2,3,4,7,8,9-HpCDF	0.005
		1,2,3,4,6,7,8,9-OCDF	0.234
$\sum$ CDDs	1.28	$\sum$ CDFs	1.77
$\sum$ Dioxin and dioxin-like compounds*	3.05		

\* $\sum$  Dioxin and dioxin-like compounds =  $\sum$  CDDs +  $\sum$  CDFs

## Section 4.4. Utilities

### Section 4.4.1. Applicability

This applies to SIC Codes 4911, 4931, and 4939 Electric Services (a crosswalk with NAICS codes is available at: <https://www.census.gov/eos/www/naics/concordances/concordances.html>). This guidance is for electric power utility boilers burning coal, wood and oil for the expressed purpose of producing steam to operate a steam generator, which, in turn, generates electricity.

### Section 4.4.2. Description/Emissions Factors for Coal-Fired Electric Utility Boilers

In 1993, the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) collaborated on assessing stack emissions of hazardous air pollutants at coal-fired power plants. As part of this project, CDD/CDF stack emissions were measured at seven U.S. coal-fired power plants (utility boilers). The levels reported for individual 2,3,7,8-substituted congeners were typically not detected or very low (i.e., #0.033 ng/Nm<sup>3</sup>). In general, CDF levels were higher than CDD levels. OCDF and 2,3,7,8-TCDF were the most frequently detected congeners. Variation in emissions between plants could not be attributed by Riggs et al. (1995) to any specific fuel or operational characteristic. The Electric Power Research Institute (EPRI) has published the results of the DOE/EPRI cooperative testing of a total of eleven plants (EPRI, 1994). The average congener emission factors derived from this eleven facility data set, as reported in EPRI (1994), are presented in Table 4-8.

**Table 4-8. Average Emission Factors (ng/kg of coal combusted) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Coal-Fired Electric Utility Boilers**

CDD Congener	Emission Factor (ng/kg coal)	CDF Congener	Emission Factor (ng/kg coal)
2,3,7,8-TCDD	0.005	2,3,7,8-TCDF	0.109
1,2,3,7,8-PeCDD	0	1,2,3,7,8-PeCDF	0.007
1,2,3,4,7,8-HxCDD	0	2,3,4,7,8-PeCDF	0.074
1,2,3,6,7,8-HxCDD	0.004	1,2,3,4,7,8-HxCDF	0.098
1,2,3,7,8,9-HxCDD	0.004	1,2,3,6,7,8-HxCDF	0.014
1,2,3,4,6,7,8-HpCDD	0.216	1,2,3,7,8,9-HxCDF	0.013
1,2,3,4,6,7,8,9-OCDD	0.517	2,3,4,6,7,8-HxCDF	0.043
		1,2,3,4,6,7,8-HpCDF	0.354
		1,2,3,4,7,8,9-HpCDF	0.087
		1,2,3,4,6,7,8,9-OCDF	0.158
∑ CDD	0.75	∑ CDF	0.96
∑ Dioxin and dioxin-like compounds*		1.71	

\*∑ Dioxin and dioxin-like compounds = ∑CDDs + ∑CDFs. Assumes non-detects = 0. Source: EPRI (1994)-11 facility data set.

**Section 4.4.3. Description/Emissions Factors for Oil-Fired Electric Utility Boilers**

Preliminary CDD/CDF emission factors for oil-fired utility boilers developed from boiler tests conducted over the past several years are reported in U.S. EPA (1995c). In 1993, the Electric Power Research Institute (EPRI) sponsored a project to gather information of consistent quality on power plant emissions. This project, the Field Chemical Emissions Measurement (FCEM) project, included testing of two cold side ESP-equipped oil-fired power plants for CDD/CDF emissions (EPRI, 1994). Table 4-9 presents CDD/CDF congener-specific emission factors (ng/L oil combusted) for oil-fired utility boilers.

**Table 4-9. Average Emission Factors (pg/L oil combusted) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Oil-Fired Utility Boilers**

<b>CDD Congener</b>	<b>Emission Factor (pg/L oil)</b>	<b>CDF Congener</b>	<b>Emission Factor (pg/L oil)</b>
2,3,7,8-TCDD	0	2,3,7,8-TCDF	0
1,2,3,7,8-PeCDD	24.7	1,2,3,7,8-PeCDF	64.1
1,2,3,4,7,8-HxCDD	63.3	2,3,4,7,8-PeCDF	49.3
1,2,3,6,7,8-HxCDD	65.8	1,2,3,4,7,8-HxCDF	76.5
1,2,3,7,8,9-HxCDD	79.7	1,2,3,6,7,8-HxCDF	35.4
1,2,3,4,6,7,8-HpCDD	477	1,2,3,7,8,9-HxCDF	0
1,2,3,4,6,7,8,9-OCDD	2055	2,3,4,6,7,8-HxCDF	23.8
		1,2,3,4,6,7,8-HpCDF	164
		1,2,3,4,7,8,9-HpCDF	0
		1,2,3,4,6,7,8,9-OCDF	0
$\Sigma$ CDD	2,765.5	$\Sigma$ CDF	413.1
$\Sigma$ Dioxin and dioxin-like compounds*	3,178.6		

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

Source: EPRI (1994) - based on two cold side ESP-equipped power plants. Calculation of emission factors assumes density of oil of 0.87 kg/L.

**Section 4.4.4. Description/Emissions Factors for Wood-Fired Electric Utility Boilers**

Congener-specific measurements of CDDs/CDFs in stack emissions from wood-fired electric utility boilers were measured by the California Air Resources Board at four facilities in 1988 (CARB, 1990b; CARB, 1990e; CARB, 1990f; CARB, 1990g). In CARB (1990b), CDDs/CDFs were measured in the emissions from a quad-cell wood-fired boiler used to generate electricity. The fuel consisted of coarse wood waste and sawdust from non-industrial logging operations. The exhaust gas passed through a multicyclone before entering the stack. In CARB (1990e), CDDs/CDFs were

measured in the emissions from two spreader stoker wood-fired boilers operated in parallel by an electric utility for generating electricity. The exhaust gas stream from each boiler is passed through a dedicated electrostatic precipitator (ESP) after which the gas streams are combined and emitted to the atmosphere through a common stack. Stack tests were conducted both when the facility burned fuels allowed by existing permits and when the facility burned a mixture of permitted fuel supplemented by urban wood waste at a ratio of 70:30. In CARB (1990f), CDDs/CDFs were measured in the emissions from a twin fluidized bed combustors designed to burn wood chips for the generation of electricity. The APCD system consisted of ammonia injection for controlling nitrogen oxides, and a multiclone and electrostatic precipitator for controlling particulate matter. During testing, the facility burned wood wastes and agricultural wastes allowed by existing permits.

In CARB (1990g), CDDs/CDFs were measured in the emissions from a quad-cell wood-fired boiler. During testing, the fuel consisted of wood chips and bark. The flue gases passed through a multicyclone and an ESP before entering the stack. The mean of the emission factors derived from the four CARB studies is used in Table 4-10 as most representative of industrial wood combustion.

**Table 4-10. Average Emission Factors (ng/kg of wood combusted) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Wood-Fired Electric Utility Boilers**

<b>CDD/CDF Congener</b>	<b>Emission Factor ng/kg wood (dry wt)</b>	<b>Emission Factor ng/kg wood (wet wt)</b>
2,3,7,8-TCDD	0.007	0.006
1,2,3,7,8-PeCDD	0.044	0.037
1,2,3,4,7,8-HxCDD	0.042	0.036
1,2,3,6,7,8-HxCDD	0.086	0.069
1,2,3,7,8,9-HxCDD	0.079	0.076
1,2,3,4,6,7,8-HpCDD	0.902	0.852
1,2,3,4,6,7,8,9-OCDD	6.026	5.367
2,3,7,8-TCDF	0.673	0.768
1,2,3,7,8-PeCDF	0.790	0.676
2,3,4,7,8-PeCDF	0.741	0.867
1,2,3,4,7,8-HxCDF	0.761	0.789
1,2,3,6,7,8-HxCDF	0.941	0.862
1,2,3,7,8,9-HxCDF	0.343	0.341
2,3,4,6,7,8-HxCDF	0.450	0.420
1,2,3,4,6,7,8-HpCDF	2.508	2.550
1,2,3,4,7,8,9-HpCDF	0.260	0.222
1,2,3,4,6,7,8,9-OCDF	1.587	1.366
$\Sigma$ CDDs	7.19	6.44
$\Sigma$ CDFs	9.05	8.86
$\Sigma$ Dioxin and dioxin-like compounds*	16.24	15.30

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

## **Section 4.5. Hazardous Waste Combustion**

### **Section 4.5.1. Applicability**

This category applies to SIC Code 4953. In particular, this guidance is applicable to commercial hazardous waste combustors (RCRA Permitted Facilities), and to boilers and industrial furnaces (BIFs) burning hazardous waste. This also includes cement kilns burning hazardous waste as supplemental fuel (SIC Code 3241), and Utilities (SIC Codes 4911, 4931, and 4939) that burn hazardous waste as supplemental fuel in the boiler. A crosswalk with NAICS codes is available at: <https://www.census.gov/eos/www/naics/concordances/concordances.html>.

### **Section 4.5.2. Emissions Factors for Commercial Boilers and Industrial Furnaces Burning Hazardous Waste (Other than Cement Kilns)**

In 1991, EPA established rules that allow the combustion of some liquid hazardous waste in industrial boilers and furnaces (Federal Register, 1991). These facilities typically burn oil or coal for the primary purpose of generating electricity. Liquid hazardous waste can only be burned as supplemental (auxiliary) fuel, and usage is limited by the rule to no more than 5 percent of the primary fuels. These facilities typically use an atomizer to inject the waste as droplets into the combustion chamber and are equipped with particulate and acid gas emission controls. In general, they are sophisticated, well controlled facilities, that achieve good combustion. Congener-specific emission concentrations for two tested boilers burning liquid hazardous waste as supplemental fuel are available (U.S. EPA, 1998). The average congener specific emission factors are presented in Table 4-11. These emission factors reflect testing at 2 of the 136 boilers/furnaces known to combust liquid hazardous waste as supplemental fuel. These facilities reflect emissions of dioxin-like compounds in 1995.

**Table 4-11. Average Emission Factors (ng/kg waste feed) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Boilers and Industrial Furnaces Burning Hazardous Waste (other than cement kilns)**

<b>CDD Congener</b>	<b>Emission Factor (ng/kg waste feed)</b>	<b>CDF Congener</b>	<b>Emission Factor (ng/kg waste feed)</b>
2,3,7,8-TCDD	0.00	2,3,7,8-TCDF	0.81
1,2,3,7,8-PeCDD	0.04	1,2,3,7,8-PeCDF	0.38
1,2,3,4,7,8-HxCDD	0.08	2,3,4,7,8-PeCDF	0.52
1,2,3,6,7,8-HxCDD	0.18	1,2,3,4,7,8-HxCDF	0.83
1,2,3,7,8,9-HxCDD	0.20	1,2,3,6,7,8-HxCDF	0.37
1,2,3,4,6,7,8-HpCDD	1.17	1,2,3,7,8,9-HxCDF	0.02
1,2,3,4,6,7,8,9-OCDD	5.24	2,3,4,6,7,8-HxCDF	0.56
		1,2,3,4,6,7,8-HpCDF	0.93
		1,2,3,4,7,8,9-HpCDF	0.16
		1,2,3,4,6,7,8,9-OCDF	0.70
$\Sigma$ CDD	6.91	$\Sigma$ CDF	5.28
$\Sigma$ Dioxin and dioxin-like compounds*	12.2		

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

### Section 4.5.3. Cement Kilns Burning Hazardous Waste as Supplemental Fuel

The high temperatures achieved in cement kilns make cement kilns an efficient technology for combusting hazardous waste as supplemental fuel. Sustaining the relatively high combustion temperatures (1,100°C to 1,500°C) that are needed to form cement clinker requires the burning of a fuel with a high energy output. Therefore, coal or petroleum coke is typically used as the primary fuel source. Because much of the cost of operating the cement kiln at high temperatures is associated with the consumption of fossil fuels, some cement kiln operators have elected to burn hazardous liquid and solid waste as supplemental fuel. Facilities that burn hazardous waste for energy recovery must comply with both RCRA and CAA regulations that specifically regulate this practice. Currently about 75 percent of the primary fuel is coal. Organic hazardous waste may have a similar energy output as coal (9,000 to 12,000 Btu/lb for coal). The strategy of combusting the waste as supplemental fuel is to off- set the amount of coal/coke that is purchased and burned by the kiln. Much of the high energy and ignitable wastes are primarily comprised of such diverse substances as waste oils, spent organic solvents, sludges from the paint and coatings industry, waste paints and coatings from the auto and truck assembly plants, and sludges from the petroleum refining industry (Greer et al., 1992). The conditions inherent in the cement kiln mimic conditions of hazardous waste incineration. For example, the gas residence time in the burning zone is typically three seconds while at temperatures in excess of 1,500°C (Greer et al.,

1992). In addition, trial burns have consistently shown that 99.99 to 99.9999 percent destruction and removal efficiencies for the very stable organic wastes can be achieved in cement kilns (Greer et al., 1992). Although the combustion of hazardous waste as supplemental or substitute fuel does have apparent advantages, only 16 percent of the Portland cement kilns (34 of the 212 kilns) combusted hazardous waste in 1995 (Federal Register, 1996b), as of 2000 only 15 plants (32 kilns) were burning hazardous waste. Other types of supplemental fuel used by these facilities include automobile tires, used motor oil, and sawdust, and scrap wood chips. The method of introducing liquid and solid hazardous waste into the kiln is a key factor to the complete consumption of the waste during the combustion of the primary fuel. Liquid hazardous waste is either injected separately or blended with the primary fuel (coal). Solid waste is mixed and burned along with the primary fuel. The pyroprocessing of raw meal in a cement kiln produces cement as fine particulates. At some facilities, cement kiln dust, which is an even finer particulate, is collected and controlled with fabric filters and/or electrostatic precipitators. Acid gases such as SO<sub>2</sub> can be formed during pyroprocessing of the sulfur-laden minerals, but the minerals have high alkalinity which neutralizes SO<sub>2</sub> gases.

Emission factors (ng/kg clinker produced) for Portland cement kilns burning hazardous waste as supplemental fuel are displayed in Table 4-12. These emission factors were developed from stack testing of CDD/CDF emissions from eleven cement kilns burning hazardous waste. The majority of stack emissions data from cement kilns burning hazardous waste were derived during trial burns, and may overestimate the CDD/CDF emissions that most kilns achieve during normal operations.

The emission factors in Table 4-12 were derived from facilities that were stack tested in 1998 and may not reflect current regulatory requirements. In 1999, EPA promulgated final standards for the stack emission limits of dioxin and dioxin-like compounds from hazardous waste combustion facilities (64 FR 52828 - 53077; Final Standards for Hazardous Air Pollutants For Hazardous Waste Combustors; Final Rule; September 30, 1999). The promulgated regulations require periodic stack sampling for dioxin-like compounds for all cement kilns burning hazardous waste. The owner/operator of such facilities is encouraged to use actual facility-specific emissions data (i.e., Approach 1) in lieu of EPA's default emission factors. Such data are the most representative and best data to use in estimating annual releases of dioxin-like compounds.

**Table 4-12. Average Emission Factors (ng per dscm) for Estimating Air Releases of Dioxin and Dioxin-Like Compounds from cement Kilns Combusting Hazardous Waste as Supplemental Fuel**

Facility	2378-TCDD	12378-PeCDD	123478-HxCDD	123678-HxCDD	123789-HxCDD	1234678-HPCDD	OCDD			
A	0.096	0.089	0.144	0.258	0.206	2.162	0.461			
B	0.028	0.014	0.009	0.008	0.010	0.043	0.459			
C	0.005	0.011	0.014	0.016	0.559	0.155	3.325			
D	0.310	0.496	0.709	1.381	1.893	6.011	0.784			
E	0.005	0.010	0.010	0.012	0.006	0.068	0.033			
F	0.007	0.009	0.006	0.012	0.013	0.057	0.201			
G	0.053	0.327	0.536	0.832	0.812	5.366	1.752			
H	0.026	0.039	0.054	0.078	0.048	0.430	0.140			
I	0.067	1.191	1.385	1.875	2.697	9.971	1.542			
J	0.035	0.041	0.048	0.047	0.044	0.216	0.091			
K	0.016	0.019	0.022	0.023	0.018	0.064	0.154			
Mean emission factor	0.059	0.204	0.267	0.413	0.573	2.231	0.813			
Facility	2378-TCDF	12378-PeDF	23478-PeCDF	123478-HxCDF	123678-HxCDF	123789-HxCDF	234678-HxCDF	1234678-HPCDF	1234789-HpCDF	OCDF
A	1.080	0.078	0.183	0.098	0.043	0.031	0.065	0.051	0.048	0.116
B	0.755	0.070	0.093	0.034	0.019	0.007	0.025	0.006	0.008	0.029
C	0.380	0.035	0.067	0.039	0.017	0.003	0.027	0.026	0.006	0.021
D	1.604	1.050	2.353	2.024	1.029	0.316	1.441	0.946	0.256	0.141
E	0.111	0.005	0.012	0.008	0.004	0.005	0.006	0.009	0.010	0.039
F	0.011	0.005	0.010	0.011	0.005	0.002	0.006	0.010	0.003	0.008
G	0.562	0.654	1.790	1.366	0.533	0.115	1.168	0.609	0.192	0.119
H	0.072	0.014	0.054	0.022	0.015	0.003	0.011	0.009	0.006	0.008
I	0.572	0.239	0.570	0.450	0.208	0.060	0.344	0.208	0.066	0.060
J	0.239	0.223	0.226	0.182	0.103	0.023	0.085	0.185	0.043	0.095
K	0.462	0.121	0.133	0.078	0.031	0.017	0.032	0.050	0.024	0.106
Mean emission factor	0.532	0.227	0.499	0.392	0.182	0.053	0.292	0.192	0.060	0.067
<b>Dioxin and dioxin-like compounds:</b>			<b>7.06 per dry standard cubic meter of stack gas</b>							

The emission factors in Table 4-12 are in units of nanogram dioxin-like compound per dry standard cubic meter (at standard temperature and pressure and adjusted to 7% oxygen) of stack gas flow. This unit is a concentration of dioxin-like compounds measured in the stack gases. The facilities listed in Table 4-12 are cement kilns burning hazardous waste, and the emission factors (expressed on a concentration basis) are the average of multiple “runs” at the same facility. A “run” is defined as a single stack sampling episode to determine the amount of dioxin-like compounds present in the gases leaving the stack. These data can be found in a database maintained by EPA’s Office of Solid Waste as documented in: Final Technical Support Document for Hazardous Waste Combustors (HWC) MACT Standards; HWC Emissions Database, Volume II; Appendix A: Cement Kilns: In: Final Standards for Hazardous Air Pollutants For Hazardous Waste Combustors; Final Rule; September 30, 1999 (64 FR 52828). This cement kiln dioxin/furan database may be accessed on the Internet at the following URL: <https://www.epa.gov/stationary-sources-air-pollution/hazardous-waste-combustors-microsoft-access-database-supplemental>.

In order to estimate annual air emissions of dioxin-like compounds using the EPA default emission factors, the owner/operator are advised to follow the calculation steps given in section 3.1.1. Please note that the EPA default emission factors are generally applicable to all Portland cement kilns burning hazardous waste regardless of primary fuel type; constituents of hazardous waste burned as supplemental fuel; air pollution control equipment installed at the kiln; temperature of the kiln and whether or not the kiln is a wet or dry process. However, the emissions of dioxin-like compounds in Table 4-12 are more representative of cement kilns that operate the air pollution control equipment at temperatures of 204° C (400° F) or less. Such temperatures are known to suppress the post combustion formation of dioxins and furans, and result in lower emissions of dioxin-like compounds than if the temperatures were more elevated.

#### **Section 4.5.4. Hazardous Waste Incineration (HWI) Facilities**

The four principal furnace designs employed for the combustion of hazardous waste in the United States are: liquid injection, rotary kiln, fixed hearth, and fluidized-bed incinerators (Dempsey and Oppelt, 1993). The majority of commercial operations are of the rotary kiln incinerator type. On-site (noncommercial) HWI technologies are an equal mix of rotary kiln and liquid injection facilities, with a few additional fixed hearths and fluidized bed operations (U.S. EPA, 1996h). Each of these HWI technologies is discussed below:

**Rotary Kiln HWI:** Rotary kiln incinerators consist of a rotating kiln, coupled with a high temperature afterburner. Because these are excess air units designed to combust hazardous waste in any physical form (i.e., liquid, semi-solid, or solid), rotary kilns are the most common type of hazardous waste incinerator used by commercial “off-site” operators. The rotary kiln is a horizontal cylinder lined with refractory material. Rotation of the cylinder on a slight slope provides for gravitational transport of the hazardous waste through the kiln (Buonicore, 1992a). The tumbling action of the rotating kiln causes mixing and exposure of the waste to the heat of combustion, thereby enhancing burnout. Solid and semi-solid wastes are loaded into the top of the kiln by an auger or rotating screw. Fluid and pumpable sludges and wastes are typically introduced into the kiln through a water-cooled tube. Liquid hazardous waste is fed directly into the kiln through a burner nozzle. Auxiliary fuel (natural gas or oil) is burned in

the kiln chamber at start-up to reach elevated temperatures. The typical heating value of hazardous waste (i.e., 8,000 Btu/kg) is sufficient to sustain combustion without auxiliary fuel (U.S. EPA, 1996h). The combustion gases emanating from the kiln are passed through a high temperature afterburner chamber to more completely destroy organic pollutants entrained in the flue gases. Rotary kilns can be designed to operate at temperatures as high as 2,580°C, but more commonly operate at about 1,100°C.

**Liquid Injection HWI:** Liquid injection incinerators (LIIs) are designed to burn liquid hazardous waste. These wastes must be sufficiently fluid to pass through an atomizer for injection as droplets into the combustion chamber. The LIIs consist of a refractory-lined steel cylinder mounted either in a horizontal or vertical alignment. The combustion chamber is equipped with one or more waste burners. Because of the rather large surface area of the atomized droplets of liquid hazardous waste, the droplets quickly vaporize. The moisture evaporates, leaving a highly combustible mix of waste fumes and combustion air (U.S. EPA, 1996h). Secondary air is added to the combustion chamber to complete the oxidation of the fume/air mixture.

**Fixed Hearth HWI:** Fixed hearths, the third principal hazardous waste incineration technology, are starved air or pyrolytic incinerators, which are two-stage combustion units. Waste is ram-fed into the primary chamber and incinerated below stoichiometric requirements (i.e., at about 50 to 80 percent of stoichiometric air requirements). The resulting smoke and pyrolytic combustion products are then passed through a secondary combustion chamber where relatively high temperatures are maintained by the combustion of auxiliary fuel. Oxygen is introduced into the secondary chamber to promote complete thermal oxidation of the organic molecules entrained in the gases.

**Fluidized-bed HWI:** The fourth hazardous waste incineration technology is the fluidized-bed incinerator, which is similar in design to that used in municipal solid waste incineration. In this configuration, a layer of sand is placed on the bottom of the combustion chamber. The bed is preheated by underfire auxiliary fuel at startup. During combustion of auxiliary fuel at start-up, the hot gases are channeled through the sand at relatively high velocity, and the turbulent mixing of combustion gases and combustion air causes the sand to become suspended (Buonicore, 1992a). This takes on the appearance of a fluid medium, hence the incinerator is termed a 'fluidized-bed' combustor. The incinerator is operated below the melting point temperature of the bed material. Typical temperatures of the fluid medium are within the range of 650 to 940°C. A constraint on the types of waste burned is that the solid waste particles must be capable of being suspended within the furnace. When the liquid or solid waste is combusted in the fluid medium, the exothermic reaction causes heat to be released into the upper portion of the combustion chamber. The upper portion is typically much larger in volume than the lower portion, and temperatures can reach 1,000°C (Buonicore, 1992a). This high temperature is sufficient to combust volatilized pollutants emanating from the combustion bed.

Most HWIs use APCDs to remove undesirable components from the flue gases that evolved during the combustion of the hazardous waste. These unwanted pollutants include suspended ash particles (particulate matter or PM), acid gases, metal, and organic pollutants. The APCD controls or collects these pollutants and reduces their discharge from the incinerator stack to the atmosphere. Levels

and kinds of these combustion byproducts are highly site-specific, depending on factors such as waste composition and incinerator system design and operating parameters (e.g., temperature and exhaust gas velocity). The APCD is typically comprised of a series of different devices that work together to clean the exhaust combustion flue gas. Unit operations usually include exhaust gas cooling, followed by particulate matter and acid gas control.

Exhaust gas cooling may be achieved using a waste heat boiler or heat exchanger, mixing with cool ambient air, or injection of a water spray into the exhaust gas. A variety of different types of APCDs are employed for the removal of particulate matter and acid gases. Such devices include: wet scrubbers (such as venturi, packed bed, and ionizing systems), electrostatic precipitators, and fabric filters (sometimes used in combination with dry acid gas scrubbing). In general, the control systems can be grouped into the following three categories: wet, dry, and hybrid wet/dry systems. The controls for acid gases (either dry or wet systems) cause temperatures to be reduced preceding the control device. This impedes the extent of formation of CDDs and CDFs in the post-combustion area of the typical HWI. It is not unusual for stack concentrations of CDD/CDFs at a particular HWI to be in the range of 1 to 100 ng CDD/CDF/dscm (Helble, 1993), which is low in comparison to other waste incineration systems. The range of total CDD/CDF flue gas concentrations measured in the stack emissions of HWIs during trial burns across the class of HWI facilities, however, has spanned four orders of magnitude (ranging from 0.1 to 1,600 ng/dscm) (Helble, 1993). The APCD systems are described below:

- **Wet Systems** : A wet scrubber is used for both particulate and acid gas control. Typically, a venturi scrubber and packed-bed scrubber are used in a back-to-back arrangement. Ionizing wet scrubbers, wet electrostatic precipitators, and innovative venturi-type scrubbers may be used for more efficient particulate control. Wet scrubbers generate a wet effluent liquid wastestream (scrubber blowdown), are relatively inefficient at fine particulate control compared to dry control techniques, and have equipment corrosion concerns. However, wet scrubbers do provide efficient control of acid gases and have lower operating temperatures (compared with dry systems), which may help control the emissions of volatile metals and organic pollutants.
- **Dry Systems** : In dry systems, a fabric filter or electrostatic precipitator (ESP) is used for particulate control. A fabric filter or ESP is frequently used in combination with dry scrubbing for acid gas control. Dry scrubbing systems, in comparison with wet scrubbing systems, are inefficient in controlling acid gases.
- **Hybrid Systems** : In hybrid systems, a dry technique (ESP or fabric filter) is used for particulate control, followed by a wet technique (wet scrubber) for acid gas control. Hybrid systems have the advantages of both wet and dry systems (lower operating temperature for capture of volatile metals, efficient collection of fine particulate, efficient capture of acid gases), while avoiding many of the individual disadvantages. In some hybrid systems, known as “zero discharge systems,” the wet scrubber liquid is used in the dry scrubbing operation, thus minimizing the amount of liquid byproduct waste.

- **Uncontrolled HWIs:** Facilities that do not use any air pollution control devices fall under a separate and unique category. These are primarily liquid waste injection facilities, which burn low ash and chlorine content wastes; therefore, they are low emitters of PM and acid gases.

For purposes of estimating emission factors, this document considers subdividing the combustors in each source category into design classes judged to have similar potential for CDD/CDF emissions. As explained below, it was decided not to subdivide dedicated HWIs.

Combustion research has identified three mechanisms involved in the emission of CDD/CDFs from combustion systems: (1) CDD/CDFs can be introduced into the combustor with the feed and pass through the system not completely burned/destroyed; (2) CDD/CDFs can be formed by chemical reactions inside the combustion chamber; and (3) CDD/CDFs can be formed by chemical reactions outside the combustion chamber. The total CDD/CDF emissions are likely to be the net result of all three mechanisms; however, the relative importance of the mechanisms can vary among source categories. In the case of HWIs, the third mechanism (i.e., post-combustion formation) is likely to dominate, because HWIs are typically operated at high temperatures and long residence times, and most have sophisticated real-time monitoring and controls to manage the combustion process. Therefore, any CDD/CDFs present in the feed or formed during combustion are likely to be destroyed before exiting the combustion chamber. Consequently, for purposes of generating emission factors, it was decided not to subdivide this class on the basis of furnace type.

Emissions resulting from the post-combustion formation in HWIs can be minimized through a variety of technologies:

- **Rapid Flue Gas Quenching:** The use of wet and dry scrubbing devices to remove acid gases usually results in the rapid reduction of flue gas temperatures at the inlet to the PM APCD. If temperature is reduced below 200°C, the low-temperature catalytic formation of CDD/CDFs is substantially retarded.
- **Use of Particulate Matter (PM) Air Pollution Control Devices:** PM control devices can effectively capture condensed and adsorbed CDD/CDFs that are associated with the entrained particulate matter (in particular, that which is adsorbed on unburned carbon containing particulates).
- **Use of Activated Carbon:** Activated carbon injection is used at some HWIs to collect (sorb) CDD/CDFs from the flue gas. This may be achieved using carbon beds or by injecting carbon and collecting it in a downstream PM APCD.

All of these approaches appear very effective in controlling dioxin emissions at dedicated HWIs, and insufficient emissions data are available to generalize about any minor differences. Consequently, for purposes of generating emission factors, it was decided not to subdivide this class on the basis of APCD type.

In 1999, EPA promulgated final standards for the stack emission limits of dioxin and dioxin-like compounds from hazardous waste combustion facilities (64 FR 52828 - 53077; Final Standards for Hazardous Air Pollutants For Hazardous Waste Combustors; Final Rule; September 30, 1999). Table 4-13 displays mean CDD/CDF emission factors for estimating air releases of dioxin and dioxin-like compounds from hazardous waste combustion facilities. The promulgated regulations require periodic stack sampling for dioxin-like compounds for all commercial hazardous waste combustion facilities. The owner/operator of such facilities is encouraged to use actual facility-specific emissions data (i.e., Approach 1) in lieu of EPA's default emission factors. Such data are the most representative and best data to use in estimating annual releases of dioxin-like compounds.

**Table 4-13. Average Emission Factors (ng/kg waste feed) for Estimating Air Releases of Dioxin and Dioxin-like Compounds from Hazardous Waste Combustion Facilities**

CDD Congener	Emission Factor (ng/kg waste feed)	CDF Congener	Emission Factor (ng/kg waste feed)
2,3,7,8-TCDD	0.14	2,3,7,8-TCDF	2.69
1,2,3,7,8-PeCDD	0.14	1,2,3,7,8-PeCDF	2.33
1,2,3,4,7,8-HxCDD	0.18	2,3,4,7,8-PeCDF	2.51
1,2,3,6,7,8-HxCDD	0.28	1,2,3,4,7,8-HxCDF	9.71
1,2,3,7,8,9-HxCDD	0.48	1,2,3,6,7,8-HxCDF	3.95
1,2,3,4,6,7,8-HpCDD	1.75	1,2,3,7,8,9-HxCDF	0.29
1,2,3,4,6,7,8,9-OCDD	3.74	2,3,4,6,7,8-HxCDF	2.70
		1,2,3,4,6,7,8-HpCDF	16.68
		1,2,3,4,7,8,9-HpCDF	1.71
		1,2,3,4,6,7,8,9-OCDF	13.46
$\Sigma$ CDD	6.71	$\Sigma$ CDF	56.03
$\Sigma$ Dioxin and dioxin-like compounds*	62.74		

\* $\Sigma$  Dioxin and dioxin-like compounds =  $\Sigma$  CDDs +  $\Sigma$  CDFs

## Section 5.0 GLOSSARY

Abatement:	Reducing the degree or intensity of, or eliminating, pollution.
Air Emission	The release or discharge of a pollutant by an owner or operator into the ambient air either by means of a stack or as a fugitive dust, mist, or vapor as a result inherent to the manufacturing, forming or combustion process.
Air Pollutant	Dust, fumes, smoke, and other particulate matter, vapor, gas, odorous substances, or any combination thereof. Also any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive substance or matter which is emitted into or otherwise enters the ambient air.
Air Pollution Control Device:	Mechanism or equipment that cleans emissions generated by a source (e.g., an incinerator, industrial smokestack, or an automobile exhaust system) by removing pollutants that would otherwise be released to the atmosphere.
Ambient Measurement	A measurement of the concentration of a substance or pollutant within the immediate environs of an organism; taken to relate it to the amount of possible exposure.
Area Source	Any source of air pollution that is released over a relatively small area but which cannot be classified as a point source. Such sources may include vehicles and other small engines, small businesses and household activities, or biogenic sources such as a forest that releases hydrocarbons
BACT-Best Available Control Technology	An emission limitation based on the maximum degree of emission reduction (considering energy, environmental, and economic impacts) achievable through application of production processes and available methods, systems, and techniques. BACT does not permit emissions in excess of those allowed under any applicable Clean Air Act provisions. Use of the BACT concept is allowable on a case by case basis for major new or modified emissions sources in attainment areas and applies to each regulated pollutant.

Boiler	A vessel designed to transfer heat produced by combustion or electric resistance to water. Boilers may provide hot water or steam.
British Thermal Unit (Btu)	Unit of heat energy equal to the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit at sea level.
CAS Registration Number	A number assigned by the Chemical Abstract Service to identify a chemical.
Combustion	1. Burning, or rapid oxidation, accompanied by release of energy in the form of heat and light. 2. Refers to controlled burning of waste, in which heat chemically alters organic compounds, converting into stable inorganics such as carbon dioxide and water.
Concentration	The relative amount of a substance mixed with another substance. An example is five ppm of carbon monoxide in air or 1 mg/l of iron in water.
Congener	A discrete chemical compound within a group of compounds having the same molecular weight and chemical/physical properties.
Cubic Feet Per Minute (CFM)	A measure of the volume of a substance flowing through air within a unit period of time.
Dioxin and Dioxin-like compounds:	CDDs and CDFs substituted with chlorine substitution in the 2,3,7, and 8-positions along the molecule. There are 7 CDDs and 10 CDFs (for a total of 17 compounds) that meet this definition.
Discharge	The release of any waste stream or any constituent thereof, into the environment.
Design Capacity	The average daily flow that a treatment plant or other facility is designed to accommodate.
Detection Limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Destruction and Removal Efficiency (DRE)	A percentage that represents the number of molecules of a compound removed or destroyed in an incinerator relative to the number of molecules entering the system (e.g., a DRE of 99.99 percent means that 9,999 molecules are destroyed for every 10,000 that enter; 99.99 percent is known as "four nines." For some pollutants, the RCRA removal requirement may be as stringent as "six nines."
Effluent Guidelines	Technical EPA documents which set effluent limitations for given industries and pollutants.
Effluent	Wastewater--treated or untreated--that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.
Emission Factor	The relationship between the amount of pollution produced and released into the environment and the amount of raw material processed, fuel consumed, or waste processed. For example, an emission factor for a blast furnace making iron would be the number of grams of dioxin-like compounds per ton of raw materials.
Emission Inventory	A listing, by source, of the amount of contaminant released into the environment per year.
Emission	Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities; from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts.
Emission Standard	The maximum amount of air polluting discharge legally allowed from a single source, mobile or stationary.
End-of-the-pipe	Technologies such as scrubbers on smokestacks and catalytic convertors on automobile tailpipes that reduce emissions of pollutants after they have formed.
Electrostatic precipitator	An air pollution control device that imparts an electric charge to particles in a gas stream causing them to collect on an electrode.
Emission Rate	The amount of a pollutant or contaminant emitted per unit of time.

Equivalent Method	Any method of sampling and analyzing for the presence and occurrence of a contaminant in an environmental sample which has been demonstrated to the EPA Administrator's satisfaction to be, under specific conditions, an acceptable alternative to normally used reference methods.
Fabric Filter	Large fabric bag, usually made of glass fibers, used to eliminate intermediate and large (greater than 20 PM in diameter) particles. This device operates like the bag of an electric vacuum cleaner, passing the air and smaller particles while entrapping the larger ones.
Flow Rate	The rate, expressed in gallons -or liters-per-hour, at which a fluid escapes from a hole or fissure in a tank. Such measurements are also made of liquid waste, effluent, and surface water movement.
Flue Gas	The products of combustion, including pollutants, emitted to the air after a production process or combustion takes place
Fossil Fuel:	Fuel derived from ancient organic remains; e.g., peat, coal, crude oil, and natural gas.
Fugitive Emissions	Emissions not caught by a capture system.
Gas Chromatography/ Mass Spectrometer	Instrument that identifies the molecular composition and concentrations of various chemicals in water and soil samples.
Grab Sample	A single sample collected at a particular time and place that represents the composition of the water, air, or soil only at that time and place.
Hazardous Waste	Wastes that possess at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special EPA lists, as defined by RCRA Subtitle C.
Incineration	An engineered process using controlled flame combustion to thermally degrade waste materials.
Industrial Process Waste	Residues produced during manufacturing operations.

Industrial Sludge	Semi-liquid residue or slurry remaining from treatment of industrial water and wastewater.
Industrial Waste	Unwanted materials from an industrial operation; may be liquid, sludge, solid, or hazardous waste.
Land Application	Discharge of wastewater, sludge or solid waste onto the surface of the ground for treatment or reuse.
Maximum Available Control Technology (MACT)	The emission standard for sources of air pollution requiring the maximum reduction of hazardous emissions, taking cost and feasibility into account. Under the Clean Air Act Amendments of 1990, the MACT must not be less than the average emission level achieved by controls on the best performing 12 percent of existing sources, by category of industrial and utility sources.
Maximum Contaminant Level	The maximum permissible level of a contaminant in water delivered to any user of a public system. MCLs are enforceable standards.
Media	Specific environments--air, water, soil--which are the subject of regulatory concern and activities.
Method Detection Limit (MDL)	See limit of detection.
Million-Gallons Per Day (MGD)	A measure of water flow.
Molecule	The smallest division of a compound that still retains or exhibits all the properties of the substance.
Monitoring	The direct measurement of the amount or concentration of a contaminant in an environmental medium.
National Emissions Standards for Hazardous Air Pollutants (NESHAPS)	Emissions standards set by EPA for an air pollutant not covered by NAAQS that may cause an increase in fatalities or in serious, irreversible, or incapacitating illness. Primary standards are designed to protect human health, secondary standards to protect public welfare (e.g., building facades, visibility, crops, and domestic animals).

National Pollutant Discharge Elimination System (NPDES):	A provision of the Clean Water Act which prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation.
Outfall	The place where effluent is discharged into receiving waters.
Particulates	1. Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. 2. Very small solids suspended in water; they can vary in size, shape, density and electrical charge and can be gathered together by coagulation and flocculation.
Performance Standards	1. Regulatory requirements limiting the concentrations of designated organic compounds, particulate matter, and hydrogen chloride in emissions from incinerators. 2. Operating standards established by EPA for various permitted pollution control systems, asbestos inspections, and various program operations and maintenance requirements.
Physical and Chemical Treatment	Processes generally used in large-scale wastewater treatment facilities. Physical processes may include air-stripping or filtration. Chemical treatment includes coagulation, chlorination, or ozonation. The term can also refer to treatment of toxic materials in surface and ground waters, oil spills, and some methods of dealing with hazardous materials on or in the ground.
Quality Assurance/Quality Control	A system of procedures, checks, audits, and corrective actions to ensure that all EPA research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality.
Receiving Waters	A river, lake, ocean, stream or other watercourse into which wastewater or treated effluent is discharged.
Representative Sample	A portion of material, medium or water that is as nearly identical in content and consistency as possible to that in the larger body of material, medium or water being sampled.
Sampling Frequency	The interval between the collection of successive samples.

Scrap	Materials discarded from manufacturing operations that may be suitable for reprocessing.
Scrubber	An air pollution device that uses a spray of water or reactant or a dry process to trap pollutants in emissions.
Site	An area or place within the jurisdiction of the EPA and/or a state.
Sludge	Any solid, semisolid or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility, or any other such waste having similar characteristics.
Smelter	A facility that melts or fuses ore, often with an accompanying chemical change, to separate its metal content. Emissions cause pollution. "Smelting" is the process involved.
Source	Any building, structure, facility or installation from which there is or may be the discharge of pollutants into the environment.
Source Characterization	Measurements made to estimate the rate of release of pollutants into the environment from a source such as an incinerator, landfill, etc.
Solid Waste	Non-liquid, non-soluble materials ranging from municipal garbage to industrial wastes that contain complex and sometimes hazardous substances. Solid wastes also include sewage sludge, agricultural refuse, demolition wastes, and mining residues. Technically, solid waste also refers to liquids and gases in containers.
Stack	Any chimney, flue, vent, roof monitor, conduit or duct arranged to discharge emissions to the air.
Standards	Norms that impose limits on the amount of pollutants or emissions produced. EPA establishes minimum standards, but states are allowed to be stricter.
Surface Water	All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.)

Technology-Based Limitations	Industry-specific effluent limitations based on best available preventive technology applied to a discharge when it will not cause a violation of water quality standards at low stream flows. Usually applied to discharges into large rivers.
Technology-Based Standards	Industry-specific effluent limitations applicable to direct and indirect sources which are developed on a category-by-category basis using statutory factors, not including water-quality effects.
Treatment Plant	A structure built to treat wastewater before discharging it into the environment. Treatment, Storage, and Disposal Facility: Site where a hazardous substance is treated, stored, or disposed of. TSD facilities are regulated by EPA and states under RCRA.
Trial Burn	An incinerator test in which emissions are monitored for the presence of specific organic compounds, particulates, and hydrogen chloride. Trichloroethylene (TCE): A stable, low boiling-point colorless liquid, toxic if inhaled. Used as a solvent or metal degreasing agent, and in other industrial applications.
Utility Boiler	Coal, oil or natural gas fired boiler used to exchange heat of combustion to steam to operate an electric generator for the expressed purpose of producing electricity. Alternative term is Power Plant.
Venturi Scrubbers	Air pollution control devices that use water to remove particulate matter from emissions
Waste Feed	The continuous or intermittent flow of wastes into an incinerator.
Waste Generation	The weight or volume of materials and products that enter the waste stream before recycling, composting, landfilling, or combustion takes place. Also can represent the amount of waste generated by a given source or category of sources
Waste Stream	The total flow of solid waste from homes, businesses, institutions, and manufacturing plants that is recycled, burned, or disposed of in landfills, or segments thereof such as the "residential waste stream" or the "recyclable waste stream."
Waste Treatment Plant	A facility containing a series of tanks, screens, filters and other processes by which pollutants are removed.

Waste Treatment Stream	The continuous movement of waste from generator to treater and disposer.
Wastewater	The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter. Water Pollution: The presence in water of enough harmful or objectionable material to damage the water's quality.
Water Quality Criteria	Levels of water quality expected to render a body of water suitable for its designated use. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.
Water Quality Standards	State-adopted and EPA-approved ambient standards for water bodies. The standards prescribe the use of the water body and establish the water quality criteria that must be met to protect designated uses.
Water Quality-Based Limitations	Effluent limitations applied to dischargers when mere technology-based limitations would cause violations of water quality standards. Usually applied to discharges into small streams.
Water Quality-Based Permit	A permit with an effluent limit more stringent than one based on technology performance. Such limits may be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry or water supply).

## Section 6.0 CONVERSION FACTORS

Abbreviation	From	Multiply by	To	Abbreviation
Length (English to Metric)				
in	inch	2.5	centimeters	cm
ft	feet	30.5	centimeters	cm
ft	feet	0.3048	meters	m
yd	yard	0.914	meters	m
mi	mile	1.609	kilometer	km
Length (Metric to English)				
cm	centimeter	0.394	inch	in
m	meter	3.281	feet	ft
m	meter	1.093	yard	yd
m	meter	39.37	inches	in
km	kilometer	0.6214	mile	mi
Length (English to English)				
ft	feet	12	inches	in
ft	feet	0.333	yards	yd
ft	feet	0.000189	miles	mi
in	inches	0.083	feet	ft
in	inches	0.028	yards	yd
mi	miles	5,280	feet	ft
mi	miles	1,760	yards	yd
Area (English to English)				
ac	acre	43,560	square feet	ft <sup>2</sup>
ac	acre	4,840	square yards	yd <sup>2</sup>
ac	acre	0.0016	square miles	mi <sup>2</sup>
ft <sup>2</sup>	square feet	0.000023	acres	ac
ft <sup>2</sup>	square feet	144	square inches	in <sup>2</sup>
ft <sup>2</sup>	square feet	0.111	square yards	yd <sup>2</sup>

Abbreviation	From	Multiply by	To	Abbreviation
in <sup>2</sup>	square inches	0.007	square feet	ft <sup>2</sup>
mi <sup>2</sup>	square miles	640	acres	ac
Area (English to Metric)				
in <sup>2</sup>	square inch	6.5	square centimeter	cm <sup>2</sup>
ft <sup>2</sup>	square foot	0.0929	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
mi <sup>2</sup>	square mile	2.59	square kilometer	km <sup>2</sup>
mi <sup>2</sup>	square mile	259	hectares	ha
ac	acre	4,047	square meters	m <sup>2</sup>
ac	acre	0.405	hectares	ha
ac	acre	0.004	square kilometer	km <sup>2</sup>
Area (Metric to English)				
cm <sup>2</sup>	square centimeter	0.16	square inch	in <sup>2</sup>
m <sup>2</sup>	square meter	10.76	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meter	1.2	square yard	yd <sup>2</sup>
km <sup>2</sup>	square kilometer	0.386	square mile	mi <sup>2</sup>
m <sup>2</sup>	square meter	0.0002471	acre	ac
ha	hectares	2.5	acre	ac
ha	hectares	107,639	square feet	ft <sup>2</sup>
ha	hectares	0.004	square miles	mi <sup>2</sup>
Volume (English to Metric)				
pt	pint	0.47	liter	L
gal	gallon	3.8	liter	L
ft <sup>3</sup>	cubic feet	0.0283	cubic meter	m <sup>3</sup>
ft <sup>3</sup>	cubic feet	28.317	liters	L
yd <sup>3</sup>	cubic yard	0.765	cubic meter	m <sup>3</sup>
cfs or ft <sup>3</sup> /s	cubic feet per second	0.0283	cubic meter/second	m <sup>3</sup> /s
cfs or ft <sup>3</sup> /s	cubic feet per second	0.646	million gallons per day	Mgal/d

Abbreviation	From	Multiply	To	Abbreviation
Mgal/d	million gallons per day	0.0438	cubic meter/second	m <sup>3</sup> /s
Mgal/d	million gallons per day	1.547	cubic feet per second	cfs or ft <sup>3</sup> /s
bb	barrels, US Petroleum	159	liters	L
Volume (Metric to English)				
mL	milliliters	0.034	fluid ounces	fl oz
L	liter	2.1	pint	pt
L	liter	1.06	quart	qt
L	liter	0.264	gallon	gal
mL	milliliter	0.034	ounces	oz
m <sup>3</sup>	cubic meter	35.31	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meter	1.31	cubic yard	yd <sup>3</sup>
m <sup>3</sup> /s	cubic meter per second	35.31	cubic feet per second	cfs or ft <sup>3</sup> /s
m <sup>3</sup> /s	cubic meter per second	22.821	million gallons per day	Mgal/d
Volume (English to English)				
bb	barrels, petroleum	42	gallons	gal
bu	bushels	1.244	cubic feet	ft <sup>3</sup>
ft <sup>3</sup>	cubic feet	1,728	cubic inches	in <sup>3</sup>
ft <sup>3</sup>	cubic feet	0.037	cubic yards	yd <sup>3</sup>
gal	gallons	0.134	cubic feet	ft <sup>3</sup>
gal	gallons	128	ounces	oz
gal	gallons	8	pints	pt
gal	gallons	4	quarts	qt
oz	once	0.001	cubic feet	ft <sup>3</sup>
Weight (English to English)				
oz	ounces	0.0625	pounds	lb
oz	ounces	437.5	grains	gr
lb	pounds	16	ounces	oz

Abbreviation	From	Multiply by	To	Abbreviation
t	tons, long	2,240	pounds	lb
t	tons, long	1.12	tons, short	t
Weight (English to Metric)				t
oz	ounces	28.35	grams	g
oz	ounces	0.028	kilogram	kg
lb	pounds	453.59	grams	g
lb	pounds	0.454	kilograms	kg
t	tons, short	0.907	metric tons	mt
t	tons, short	907	kilograms	kg
t	tons, long	1.016	metric tons	mt
Weight (Metric to English)				
g	grams	0.002	pounds	lb
g	grams	15.43	grains	gr
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
kg	kilograms	0.0011	tons, short	t
kg	kilograms	0.001	tons, long	t
mt	metric tons	0.984	tons, long	t
mt	metric tons	1.102	tons, short	t
mt	metric tons	2,204.6	pounds	lb
Temperature				
°F	degrees Fahrenheit	$5/9 * (°F-32)$	degrees Celsius	°C
°C	degrees Celsius	$9/5 * (°C +32)$	degrees Fahrenheit	°F
Concentration				
mg/L	milligrams per liter	1	parts per million	ppm
ppm	parts per million	1	milligrams per liter	mg/L

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