United States
Environmental Protection
Agency

The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update

emission limits are specific to the sum of CDD and CDF emissions (the sum of tetra through octa CDDs and CDFs). For either new or existing MWIs that were operational before or after June 20, 1996, EPA limits the total CDD/CDF concentration in the stack gases to 2.3 ng/dscm. This would require the application of wet scrubbers, dry sorbent injection of activated carbon combined with fabric filters and/or spray dryers and fabric filters. EPA expects that many facilities which currently operate onsite incinerators will switch to less expensive methods of treatment and disposal of medical and infectious waste when faced with the compliance costs associated with the emission standards for MWIs. EPA projects that, following full compliance with these standards, annual emissions from MWIs will be 5 to 7 g I-TEQ_{DF}/yr.

3.4. CREMATORIA

3.4.1. Human Crematoria

3.4.1.1 *Emissions Data*

Bremmer et al. (1994) measured CDD/CDF emissions at two crematoria in the Netherlands. The first, a "cold"-type furnace with direct, uncooled emissions, was calculated to yield 2,400 ng I-TEQ_{DF} per body. In the cold-type furnaces, the coffin is placed inside at a temperature of about 300 °C. The temperature of the chamber is then increased to 800 to 900 °C using a burner and kept there for 2 to 2.5 hr. The second furnace, a "warm" type in which flue gases are cooled to 220 °C prior to discharge, was calculated to yield 4,900 ng I-TEQ_{DF} per body. In the warm-type furnace, the coffin is placed in a chamber preheated to 800 °C or higher for 1.2 to 1.5 hr. The chamber exhausts from both furnace types were incinerated in an afterburner at a temperature of about 850 °C. The higher emission rate for the warm-type furnace was attributed by the authors to the formation of CDDs/CDFs during the intentional cooling of the flue gases to 220 °C.

Jager et al. (1992) (as reported in Bremmer et al., 1994) measured an emission rate of 28,000 ng I-TEQ_{DF} per body for a crematorium in Berlin, Germany. No operating process information was provided by Bremmer et al. for the facility.

Mitchell and Loader (1993) reported even higher emission factors for two crematoria in the United Kingdom. The first facility tested was manually operated and had primary and secondary combustion chambers preheated to 650 °C and a residence time of 1 sec in the secondary combustion chamber. The second tested facility was computer controlled and had primary and secondary combustion chambers heated to 850 °C and a residence time of 2 sec in the secondary combustion chamber. The measured stack gas TEQ concentrations ranged from 42 to 71.3 ng I-TEQ_{DF}/m^3 (at 11% oxygen) at the first facility and from 25.4 to 45.5 ng I-TEQ_{DF}/m^3 (at 11% oxygen) at the second facility. Emission factors based on these test results and gas generation rates reported by Bremmer et al. (1994) were calculated to range from 70,000 to 80,000 ng I-TEQ_{DF}/body (HMIP, 1995).

Takeda et al. (1998) measured CDD/CDF emissions at 10 crematoria in Japan. Although there are more than 1,600 crematoria in Japan, the 10 tested facilities handle 4% of the cremations carried out in Japan annually. A wide range of CDD/CDF emissions were observed. When nondetect values were treated as zero, the emission factor range was 42 to 62,000 ng I-TEQ_{DF}/body (mean of 9,200 ng I-TEQ_{DF}/body). When nondetect values were treated as one-half the DL, the range was 450 to 63,000 ng I-TEQ_{DF}/body (mean of 11,000 ng I-TEQ_{DF}/body).

To obtain more data on CDD/CDF emissions from crematoria in Japan, Takeda et al. (2001) measured CDD/CDF emissions at 17 additional crematoria. In that study, all the crematoria except one had secondary combustion chambers. Additionally, one crematorium had a secondary combustion chamber but did not use it. One to four main chambers were connected to the secondary chambers, and the temperature of the main chambers ranged from approximately 650 to 1,150 °C. In most cases, only one body was cremated at time. However, between two and four bodies were cremated at four sampling events. A coffin and any accompanying materials were combusted along with the body. Emission factors ranged from 120 to 24,000 ng I-TEQ_{DF}/body. In general, as the average temperature in the main combustion chamber increased, CDD/CDF emissions decreased. However, the crematorium that had a secondary combustion chamber but did not use it had both high temperatures in the main combustion chamber and high CDD/CDF emissions. Additionally, with the rise of the average temperature in the secondary combustion chamber of the eight crematoria without dust collectors, CDD/CDF emissions decreased. For crematoria with dust collectors, the relationship between the average temperature in the secondary combustion chamber and CDD/CDF emissions was not clear.

EPA obtained test data from two crematoria for humans operating in the United States, one at Camellia Memorial Lawn in California (CARB, 1990c) and one at Woodlawn Cemetery in New York (U.S. EPA, 1999f). Additionally, EPA obtained test data from one crematorium for animals operating in the United States: University of Georgia Veterinary School (U.S. EPA, 2000e); however, it is not appropriate to use the emission factors from this facility to characterize emissions associated with human cremation.

Testing at the Camellia Memorial Lawn crematorium, which is classified as a warm-type facility using the criteria of Bremmer et al. (1994), was conducted in 1990 (CARB, 1990c). The combusted material at this facility consisted of the body, as well as 4 pounds of cardboard, up to 6 pounds of wood, and an unquantified amount of unspecified plastic wrapping. The three emission tests conducted at this facility, which operates using an afterburner, yielded an average emission factor of 543 ng TEQ_{DF}-WHO_{98}/body (501 ng I-TEQ_{DF}/body). Table 3-28 presents the congener-specific emission factors for this facility.

Testing at Woodlawn Cemetery, which has a crematorium with a primary combustion chamber, a secondary combustion chamber, and a scrubber APCD, was conducted in 1995. Tests were run at three secondary combustion chamber temperatures: 675, 870, and 980 °C (U.S. EPA, 1999f). The combusted material consisted of the body, as well as a 10- to 100-pound casket constructed of fiberboard, particle board, or wood and various body wrappings and articles such as a plastic sheet, a cloth sheet, or clothes. For this facility, average emission factors of 325 and 961 ng TEQ_{DF}-WHO_{98}/body cremated (310 and 780 ng I-TEQ_{DF}/body cremated) were calculated, based on emissions collected at the scrubber inlet and outlet, respectively. The congener-specific emission factors for this facility are shown in Table 3-29.

In 1995, 1,155 crematoria were reported to be operating in the United States; this number had decreased to approximately 1,060 by 2000. To determine whether the emissions data collected at the Woodlawn Cemetery facility are representative of a typical crematorium operating in the United States, representatives from the Cremation Association of North America (CANA) were contacted to identify the typical operating conditions at U.S. crematoria. According to the CANA representatives, all crematoria operating in the United States have primary and secondary combustion chambers. Additionally, crematoria with operating conditions that indicate the presence of an afterburner are considered to contain secondary combustion chambers. The primary and secondary combustion chambers at U.S. crematoria typically operate at between 675 and 870 °C, but many operate at 980 °C, as required by their respective states.

Only one or two facilities in the United States incorporate the use of an APCD, such as a scrubber. Therefore, the inlet dioxin emission factors rather than the outlet dioxin emission factors at the Woodlawn crematorium would be representative of a typical crematorium operating in the United States (telephone conversation between Allen Krobath, CANA, and K. Riley, Versar, Inc., February 12, 2003, and telephone conversation between Dale Walter, Mathews Cremation, and K. Riley, Versar Inc., February 13, 2003).

In the previous inventory, an average emission factor of 17,000 ng I-TEQ_{DF}/body (assuming nondetect values are zero) was developed, based on emission factors measured for 16 of the tested facilities, including the one at Camellia Memorial Lawn (CARB, 1990c), the 10 Japanese facilities (Takeda et al., 1998), the two Dutch facilities (Bremmer et al., 1994), the one German facility (Jager et al., 1992), and the two British facilities (Mitchell and Loader, 1993). The more recent data provided by Takeda et al. (2001) for the 17 Japanese facilities support the emission factor of 17,000 ng I-TEQ_{DF}/body. However, an average emission factor developed using the data reported for the two U.S. crematoria (i.e., the outlet values for the Camellia Memorial Lawn facility and the inlet values for the Woodlawn Cemetery facility) is 434 ng TEQ_{DF}-WHO_{98}/body (410 I-TEQ_{DF}/body cremated), assuming nondetect values are zero. These values are two orders of magnitude less than the overall average calculated above. An examination of the differences in U.S. and foreign operating practices may provide a rationale for the large discrepancies.

Bremmer et al. (1994) reported an emission factor of 2,400 ng I-TEQ_{DF}/body for a Dutch facility with a cold-type furnace and an emission factor of 4,900 ng I-TEQ_{DF}/body for another Dutch facility with a warm-type furnace where flue gases were cooled to 220 °C. Neither of the U.S. facilities are considered to have cold-type furnaces. Additionally, the flue gases at the Camellia Memorial Lawn crematorium were not cooled prior to exiting the furnace. At the Woodlawn Cemetery facility, the flue gases were cooled from 681 to 860 °C prior to entering the scrubber to 271 to 354 °C by the time they exited the scrubber and the furnace. The emissions were higher at the scrubber outlet than at the inlet (961 vs. 325 ng TEQ_{DF}-WHO_{98}/body [780 vs. 319 I-TEF/body]); however, the emissions were not on the same magnitude as reported by Bremmer for the warm-type facility (4,900 ng I-TEQ_{DF}/body). The Jager et al. (1992) report did not include operating process information; therefore the German facility could not be compared with the U.S. facilities. Additionally, the emission values derived from the Mitchell and Loader

(1993) emission concentrations were calculated using gas generation rates from the Bremmer et al. report and, as such, may not be indicative of crematoria in the United States.

In the Takeda et al. (1998, 2001) reports, the burn time for the cremations varied from 47 to 117 min. The average burn time in the U.S. studies was 120 min. This shorter burn time may not be optimal for dioxin reduction, resulting in higher dioxin emissions. Also, the secondary combustion chamber temperatures ranged from 250 to 950 °C in the Takeda studies, again resulting in higher emission rates. In fact, in Takeda et al. (2001) two of the three runs that had the highest TEQ concentrations per body came from a crematorium that did not use a secondary combustion chamber. Of the 31 crematoria sampled in Takeda et al. (2001), 26 had lower than 5,000 ng I-TEQ_{DF}/body.

Because the Woodlawn facility is unique in that it incorporates an APCD, the sample data for the air stream entering the scrubber versus the stream exiting the scrubber should be analyzed. A comparison of the dioxin concentrations of these air streams shows a significant increase in dioxin concentrations in the stream exiting the scrubber. This increase can be attributed to the decrease in temperature that occurred in the scrubber. Upon exiting the scrubber, the flue gas temperatures were in the range of 271 to 354 °C, compared with temperatures of between 681 and 860 °C at the scrubber inlet. As discussed in Section 2, these exit flue gas temperatures lie in the optimum temperature range for dioxin formation; therefore, an increase in dioxin concentrations would be expected.

An analysis of scrubber inlet dioxin data indicates that the average dioxin concentrations increased with temperature (189, 445, and 503 ng TEQ_{DF}-WHO_{98}/body at 681, 772, and 860 °C, respectively). Because the operating temperatures are outside the temperature range for the formation of dioxin (200 to 400 °C), dioxin concentrations should decrease as temperatures increase. Further analysis of the data shows that as temperatures at the scrubber inlet increased, so did concentrations of PM, HCl, and lead (Table 3-30). The data also indicate that oxygen levels decreased as the temperature increased (U.S. EPA, 1999). Given these data, one could speculate that as the temperature increased, incomplete combustion conditions arose, leading to an increase in dioxin formation.

Using data from U.S. crematoria, EPA recommends an average emission factor of 434 ng TEQ_{DF}-WHO_{98}/body (410 ng I-TEQ_{DF}/body). This is derived from the scrubber inlet dioxin concentrations from the Woodlawn Cemetery study and the results from the Camellia Memorial

Lawn study. These average congener-specific emission are presented in Table 3-31, and the CDD/CDF congener and congener group emission profiles are presented in Figure 3-17. Because the emission factor was derived using emissions data from only 2 of 1,060 crematoria, the average emission factor is assigned a low confidence rating.

3.4.1.2. *Activity Level Information*

A total of 323,371 cremations were performed in reference year 1987; 488,224 in 1995; and 629,362 in 2000. A high confidence rating is assigned to these activity level estimates because they are based on comprehensive data provided by CANA (CANA, 2002; Springer, 1997).

3.4.1.3. *Emission Estimates*

Combining the average emission rate of 434 ng WHO-TEQ_{98}/body (410 ng I-TEQ_{DF}/body) with the number of cremations in 1987, 1995, and 2000 (323,371; 488,224; and 629,362, respectively) yields an estimated annual release of 0.14 g TEQ_{DF}-WHO_{98} (0.14 g I-TEQ_{DF}) in 1987, 0.21 g TEQ_{DF}-WHO_{98} (0.2 g I-TEQ_{DF}) in 1995, and 0.27 g TEQ_{DF}-WHO_{98} (0.26 g I-TEQ_{DF}) in 2000. An overall confidence rating of low was assigned to the emissions, since the emission factor had a low rating.

3.4.2. Animal Crematoria

3.4.2.1. *Emissions Data*

Only one study that measured CDD/CDF emissions from animal cremation could be located. In 1999, CDD/CDF emissions were measured from a newly installed animal incineration unit located at the University of Georgia Veterinary School (U.S. EPA, 2000e). The incineration unit, which consists of a primary and a secondary combustion chamber, is used to dispose of animals (mostly cows and horses) used in experimentation. Emissions are uncontrolled, with the exception of an NFPA spark screen located at the stack outlet. Based on four test runs, the average TEQ emission factor was 0.12 TEQ_{DF}-WHO_{98}/kg (0.11 ng I-TEQ_{DF}/kg) of animal cremated. The average emission factors for these test runs are provided in Table 3-32 and a congener-specific profile based on these data is provided as Figure 3-18.

Table 3-28. Congener-specific profile for Camellia Memorial Lawn Crematorium

Congener/congener group	Mean facility emission factor	
	Assuming nondetect set to zero (ng/body)	Assuming nondetect set to ½ detection limit (ng/body)
2,3,7,8-TCDD	28.9	28.9
1,2,3,7,8-PeCDD	89.6	89.6
1,2,3,4,7,8-HxCDD	108	108
1,2,3,6,7,8-HxCDD	157	157
1,2,3,7,8,9-HxCDD	197	197
1,2,3,4,6,7,8-HpCDD	1,484	1,484
OCDD	2,331	2,331
2,3,7,8-TCDF	206	206
1,2,3,7,8-PeCDF	108	117
2,3,4,7,8-PeCDF	339	349
1,2,3,4,7,8-HxCDF	374	374
1,2,3,6,7,8-HxCDF	338	338
1,2,3,7,8,9-HxCDF	657	657
2,3,4,6,7,8-HxCDF	135	135
1,2,3,4,6,7,8-HpCDF	1,689	1,813
1,2,3,4,7,8,9-HpCDF	104	112
OCDF	624	624
Total 2,3,7,8-CDD	4,396	4,396
Total 2,3,7,8-CDF	4,574	4,725
Total I-TEQ_{DF}	501	508
Total TEQ_{DF}-WHO_{98}	543	550
Total TCDD	554	554
Total PeCDD	860	860
Total HxCDD	2,224	2,224
Total HpCDD	3,180	3,180
Total OCDD	2,331	2,331
Total TCDF	4,335	4,335
Total PeCDF	2,563	2,563
Total HxCDF	4,306	4,306
Total HpCDF	2,030	2,154
Total OCDF	624	624
Total CDD/CDF	23,007	23,131

Source: CARB (1990c).

Table 3-29. Congener-specific profile for the Woodlawn Cemetery crematorium

Congener	Mean emission factor, scrubber inlet (ng/body)		Mean emission factor, scrubber outlet (ng/body)	
	Nondetect set to zero	Nondetect set to ½ detection limit	Nondetect set to zero	Nondetect set to ½ detection limit
2,3,7,8-TCDD	11	12	39	45
1,2,3,7,8-PeCD	31	44	168	364
1,2,3,4,7,8-HxCDD	74	74	239	258
1,2,3,6,7,8-HxCDD	115	115	565	603
1,2,3,7,8,9-HxCDD	83	83	524	553
1,2,3,4,6,7,8-HpCDD	724	724	1,253	1,302
OCDD	1,120	1,120	10,698	1,154
2,3,7,8-TCDF	106	106	256	279
1,2,3,7,8-PeCDF	116	116	150	170
2,3,4,7,8-PeCDF	285	285	409	463
1,2,3,4,7,8-HxCDF	263	264	252	280
1,2,3,6,7,8-HxCDF	278	278	253	282
1,2,3,7,8,9-HxCDF	146	146	139	148
2,3,4,6,7,8-HxCDF	466	466	429	474
1,2,3,4,6,7,8-HpCDF	962	963	872	948
1,2,3,4,7,8,9-HpCDF	165	165	142	148
OCDF	435	435	3,499	363
Total I-TEQ_{DF}	319	329	780	780
Total TEQ_{DF}-WHO_{98}	325	341	961	961

Source: U.S. EPA (1999f).

Table 3-30. Operational data for the Woodlawn Cemetery crematorium, scrubber inlet

Parameter	Mean value		
	675 °C	870 °C	980 °C
Particulate matter (gr/dscf @ 7% O_2)	0.015	0.033	0.068
Hydrochloric acid (lb/hr)	0.053	0.14	0.26
Lead (g/hr)	0.1	0.32	0.59
Oxygen (%)	9.9	8.6	7.5

Source: U.S. EPA (1999f).

Table 3-31. Congener-specific profile for the Camellia Memorial Lawn Crematorium and the Woodlawn Cemetery crematorium

Congener/congener group	Mean facility emission factor (ng/body)	
	Nondetect set to zero	Nondetect set to ½ detection limit
2,3,7,8-TCDD	20	20
1,2,3,7,8-PeCDD	67	60
1,2,3,4,7,8-HxCDD	91	91
1,2,3,6,7,8-HxCDD	136	136
1,2,3,7,8,9-HxCDD	140	140
1,2,3,4,6,7,8-HpCDD	1,104	1,104
OCDD	1,721	1,721
2,3,7,8-TCDF	156	156
1,2,3,7,8-PeCDF	112	117
2,3,4,7,8-PeCDF	312	317
1,2,3,4,7,8-HxCDF	319	319
1,2,3,6,7,8-HxCDF	308	308
1,2,3,7,8,9-HxCDF	401	401
2,3,4,6,7,8-HxCDF	300	300
1,2,3,4,6,7,8-HpCDF	1,326	1,387
1,2,3,4,7,8,9-HpCDF	135	138
OCDF	530	530
Total I-TEQ_{DF}	410	329
Total TEQ_{DF}-WHO_{98}	434	341
Total TCDD	467	467
Total PeCDD	838	838
Total HxCDD	1,923	1,923
Total HpCDD	2,384	2,384
Total OCDD	1,721	1,721
Total TCDF	3,586	3,586
Total PeCDF	2,441	2,441
Total HxCDF	3,575	3,575
Total HpCDF	1,897	1,958
Total OCDF	530	530
Total CDD/CDF	19,362	19,424

Source: CARB (1990c); U.S. EPA (1999f).